I. C. 7143 December 1940

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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## INFORMATION CIRCULAR

# ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL, FISCAL YEAR 1940

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**ARNO C. FIELDNER AND W. E. RICE**

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# ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL, FISCAL YEAR 1940[1]

By Arno C. Fieldner[2] and W. E. Rice[3]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7143."

[2] Chief, Technologic Branch, and chief engineer, Coal Division, Bureau of Mines, Washington, D. C.

[3] Fuel engineer, Coal Division, Bureau of Mines, Washington, D. C.

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## INTRODUCTION

This is the fifth of a series of annual reports[4] of technologic investigations conducted by the Bureau of Mines on the occurrence, properties, mining, preparation, and uses of coal. The research of the Bureau is carefully coordinated with the requirements of the producing and consuming industries, with a view to conservation of resources of coal in mining and use, and conservation of the health and lives of workmen employed in these industries. Such coordination is facilitated by the wide range of specialization of the several groups engaged in studies concerning coal. Here are reported correlated studies ranging from paleobotanic analysis of the formation of coal as it occurred some millions of years ago to the effect of mechanical methods of mining on present-day employment in mines.

As this is a summary of the current work of the Bureau of Mines, so the Bureau likewise has provided a condensed review of the outstanding current work of others on research and technology of coal.[5]

## ACKNOWLEDGMENTS

Material for this report was supplied by the following members of the staff of the Technologic Branch of the Bureau of Mines:

### Coal Division

J. F. Barkley, supervising engineer, fuel economy service section.
H. M. Cooper, supervising chemist, coal analysis section.
J. D. Davis, supervising chemist, coal carbonization section.

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[4] Fieldner, A. C., Resumé of Research and Technologic Work Relating to Coal Conducted by the Technologic Branch During 1936: Bureau of Mines Inf. Circ. 6935, 1937, 14 pp.
Fieldner, A. C., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1937: Bureau of Mines Inf. Circ. 6992, 1938, 44 pp.
Fieldner, A. C., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1938: Bureau of Mines Inf. Circ. 7052, 1939, 44 pp.
Fieldner, A. C., and Brewer, R. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1939: Bureau of Mines Inf. Circ. 7105, 1940, 59 pp.

[5] Fieldner, A. C., Developments in Coal Research and Technology in 1937 and 1938: Bureau of Mines Tech. Paper 613, 1940, 95 pp.

H. P. Greenwald, superintendent, Central Experiment Station, and supervising engineer, experimental coal-mine section.
P. Nicholls, supervising engineer, fuels section.
V. F. Parry, supervising engineer, subbituminous coal and lignite section.
W. A. Selvig, supervising chemist, coal constitution and miscellaneous analysis section.
N. H. Snyder, supervising engineer, fuel-inspection section.
H. H. Storch, supervising chemist, coal-hydrogenation and physical-chemistry section.

## Explosives Division

W. J. Huff, consulting explosives chemist.
J. C. Holtz, gas engineer.
G. W. Jones, chemist.
J. E. Tiffany, explosives testing engineer.

## Mining Division

C. F. Jackson, chief engineer.
L. C. Ilsley, supervising engineer, electrical-mechanical section.
G. E. McElroy, supervising engineer, mine-ventilation section.
A. L. Toenges, supervising engineer, coal-mining section.

## Nonmetals Division

O. C. Ralston, chief engineer.
W. H. Coghill, supervising engineer, Southern Experiment Station.
H. F. Yancey, supervising engineer, Northwest Experiment Station.

In addition to the research of the Technologic Branch, closely related work of other branches of the Bureau of Mines is discussed in this report and acknowledgment is made to:

## Health and Safety Branch

D. Harrington, chief.
H. H. Schrenk, chief chemist, Health Division.
J. J. V. Forbes, supervising engineer, instruction and emergency section, Safety Division.

## Economics and Statistics Branch

E. W. Pehrson, acting chief.

Acknowledgment is made also of the cooperation of the following institutions and organizations:

American Society for Testing Materials.
Bituminous Coal Research, Inc.
Canadian Bureau of Mines.
Carnegie Institute of Technology.
Colorado School of Mines.
Federal Works Agency, Work Projects Administration.
Hillman Coal & Coke Co.
Northern Colorado Coals, Inc.
Oregon Department of Geology and Mineral Industries.
Pennsylvania State College.
State Geological Survey of Illinois.
University of Alabama.
University of North Dakota.
University of Washington.

## PROPERTIES AND COMPOSITION OF AMERICAN COALS

### Inspection, Sampling, and Analysis

Four coal-sampling trucks are operated in the United States. These carry equipment for crushing and quartering samples, and two have facilities for making screen analyses to determine the size of coal. Field sampling was directed principally toward satisfying the need for analyses in connection with the awarding of contracts to supply coal to agencies of the Government.

Coal was inspected and samples collected at 8 mines in Ohio, 104 mines in Kentucky, 10 mines in Tennessee, 20 mines in West Virginia, 1 mine in Virginia, 48 mines in Indiana, 18 mines in Illinois, 12 mines in Kansas, 14 mines in Missouri, 3 mines in Iowa, 1 mine in Oklahoma, and at 11 bituminous coal-mines and 18 anthracite breakers in Pennsylvania.

In a survey of coal lands of the Tennessee Valley samples were collected at one mine in Georgia and three mines in Tennessee; moreover, 196 face samples were collected from old test pits, drifts, and wagon mines in Georgia, Alabama, and Tennessee.

In the investigation of subbituminous coal and lignite six mines in Wyoming were visited, and 8 samples of subbituminous coal were obtained for analysis and experimental study of physical and chemical properties; 3 samples were obtained from Montana; and 29 samples were obtained for further studies in the Northern Colorado field.

The coal-analysis laboratory received and analyzed 13,058 samples during the year; 8,310 of these were related directly to the purchase and use of coal and coke by agencies of the Government and 4,748 were related to research of the Bureau of Mines on sampling, analysis, combustion, carbonization, hydrogenation, and safety in mines. The work on safety in mines was especially active, and 3,047 samples were analyzed in connection with studies of the explosibility of dust in coal mines and the prevention of fires and explosions.

## Properties of Coals of Oregon

In cooperation with the State of Oregon Department of Geology and Mineral Industries coals currently mined in Oregon were investigated.[6] Samples were obtained from the seven operating properties and two prospects in the State. Eight of the coals are subbituminous, and one is lignite. None has coking properties. The coals of the Coos Bay field, which comprise most of those studied, are characterized by a high content of moisture, moderate ash, low sulfur, and heating values from 9,260 to 10,080 B.t.u. per pound as received. Friability tests indicated that all of the coals are resistant to breaking during handling, but all will slack to some extent, and most of them are strongly slacking and therefore will not withstand storage during dry weather unless loss of moisture can be prevented. In low-temperature carbonization assays the char produced is a smokeless fuel of high quality; the products are 47 to 70 percent char, 6 to 11 percent gas with heating value from 450 to 730 B.t.u. per cubic foot, 4 to 12 percent tar and oil, and 16 to 37 percent water. Tests of one of the coals showed that 88 percent or more of the moisture- and ash-free coal can be liquefied by hydrogenation. Burning tests with an overfeed domestic stoker in a hot-water boiler demonstrated that Coos Bay coals can be burned satisfactorily and with high efficiency in equipment of this type. A washability study of one coal of high ash content showed that it has such a large proportion of associated impurities that washing is not feasible.

## Classification

For several years, under the sponsorship of the American Society for Testing Materials, the Bureau of Mines has cooperated with other scientific institutions in the United States and Canada in the development of a standard classification of coal that would provide a common language for describing American coals.[7] Such a classification is of value for coordinating research and testing work, preparing purchase specifications, and settling disputes and litigation with respect to price fixing, transportation rates, and import duties.

Although the classification has become standardized,[8] the Bureau of Mines from time to time has made tests or assisted in the standardization of tests to aid in the classification of borderline coals and has studied the advisability of making suggested changes in the specifications for the classification of various ranks of coal.

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[6] Yancey, H. F., and Geer, M. R., Analyses and Other Properties of Oregon Coals as Related to Their Utilization: Oregon Dept. Geol. and Min. Ind. Bull. 20, 1940, 38 pp.

[7] American Society for Testing Materials, Standard Specifications for Classification of Coal by Rank, A.S.T.M. Designation D388-38: A.S.T.M. Standards, 1939, part III, Nonmetallic Materials - General, pp. 1-6.

[8] Fieldner, A. C., Fourth Standandard Completes Classification of Coals: Industrial Standardization, vol. 10, December 1939, pp. 303-306; The Mississippi Valley Lumberman, vol. 71, January 19, 1940, pp. 50-52.

## Study of Borderline Between Lignitic and Subbituminous C Coals

A suggestion has been made that the boundary line between lignitic and subbituminous C coals in the Standard Specifications for Classification of Coals by Rank possibly should be raised from 8,300 to 8,500 B.t.u., as some of the Saskatchewan (Canada) coals that are believed to be lignitic are placed in the subbituminous C class according to analysis. Therefore, charts prepared several years ago by the Bureau of Mines in a study of classification were examined to determine whether the suggested change in boundary line would affect the classification of some of the coals of western United States. The conclusions of this examination were that the change would not affect most coals but that there are certain fields in which the change would not be advisable according to present data.

## Moisture Characteristics

The specifications for classification of coal by rank specify that the lower-rank coals shall be classified according to B.t.u. on the moist basis, that is, coal containing the natural bed moisture. Certain coals, in addition to the natural bed moisture, show visible surface moisture caused by infiltration of underground water to the coal bed; others, when sampled, may contain less than the true bed moisture owing to evaporation of this moisture in dry, well-ventilated mines. To determine the true bed moisture of those coals that appeared either too wet or too dry Stansfield and Gilbart, of the Research Council of Alberta, in their studies of the moisture characteristics of coal have devised a test to determine the moisture-holding capacity of coal at 100 percent humidity, which is assumed to be equal to the bed moisture of the coal.

The Bureau of Mines, in cooperation with the Canadian Bureau of Mines, is studying this test and as the first step in the investigation is determining how well the two laboratories can check the moisture values obtained on the same coal by this method. In the tests that have been completed good check results have been obtained, which indicate that the method will give results that can be duplicated readily.

## Slacking Characteristics

Low-rank coals of the lignitic and subbituminous class have a pronounced tendency to disintegrate or "slack" when alternately dried and wetted by exposure to the weather. This troublesome property causes the coarser sizes to break into an excessive amount of fine material with consequent decrease in value for most combustion purposes. Aside from this, coals that slack in storage ignite spontaneously because of the greater surface exposed to oxidation. In the classification of coal the slacking characteristic is sometimes the only property that will determine whether a particular coal is to be classified as bituminous or subbituminous.

The slacking tendencies of coals can be measured by an accelerated laboratory test developed by the Bureau of Mines. In this method the coal

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is alternately dried and wetted, and the amount of disintegration is measured by determining the proportion passing through a sieve with one-quarter-inch square openings. During this year the slacking test was made on five samples from Washington, two from Oregon, one from New Mexico, and one from western Kentucky in connection with the classification of these coals and the relation of physical and chemical properties to utilization.

## Determination of Ash of Coals High in Calcite and Pyrite

Cooperative tests were completed by the Bureau of Mines and the Illinois Geological Survey on the determination of ash of five coals high in calcite and pyrite. Appreciable amounts of calcite and pyrite in a coal cause difficulties in making satisfactory check determinations of ash because varying amounts of sulfur, depending on the rate of heating, are retained as calcium sulfate in the ash. Ash was determined by the following methods, which comply with the A.S.T.M. standard method of determining ash of coal and coke: (1) Rapid heating of the sample on the hearth of a hot furnace to expel volatile matter, then at 750°C. to constant weight, (2) slow heating by starting in a cold furnace and heating to 750°C. in 2 hours, (3) slow heating by starting in a cold furnace and heating to 400°C. in one-half hour, a further half hour at 400°C., and then transferring the sample to another furnace previously heated to 750°C. Reference determinations were made by Parr's sulfated-ash procedure, whereby all of the calcite is converted to calcium sulfate and a correction applied from the percentage of carbon dioxide in the coal.

Results obtained by the two laboratories agree closely when the determination is started in a cold furnace and the ash heated to 750°C. in 2 hours, then to constant weight. By this procedure much of the sulfur of the pyrite is oxidized and expelled before the calcite is decomposed, less sulfur is retained as calcium sulfate by the ash, and a lower percentage of ash is indicated. The method using two furnaces also gives satisfactory results. The rapid-heating method, in which determination of ash is begun in a hot furnace, indicates higher ash contents for coals high in calcite because much of the sulfur is fixed in the ash.

The tests also show that determinations of ash begun in a cold furnace and heated to 750°C. in 2 hours, and results by Parr's sulfated-ash procedure, check within 0.5 percent for coals that contain up to 3.6 percent carbon dioxide. This check result is within the tolerance of the American Society for Testing Materials for the determination by different laboratories of ash of coals containing carbonates. The method beginning in a hot furnace, by a similar comparison, gives results within the 0.5-percent tolerance only for coals containing less than 0.5 percent carbon dioxide.

## Crucible Swelling Test

Tests during the previous year showed that swelling of the coal in the crucible test of the British Standards Institution bears no relationship to the amount of expansion of the same coal in an experimental coke oven but promises to be a useful indicator of the caking of coals when burned on grates; therefore a study of this method of test has been continued by Committee D-5 of the American Society for Testing Materials. As one step in this study several laboratories, including the Bureau of Mines, made cooperative tests to determine how well the swelling number of the same sample of coal can be checked. The results showed that various laboratories can check the swelling index closely if the instructions as to the type, size, and location of the gas burner used to heat the crucible are followed closely.

## COAL MINING

### Experimental Coal Mine

### Bearing Strength and Compressibility of Pillars

A paper was published summarizing work on square pillars comprising the entire height of the Pittsburgh coal bed in the Experimental coal mine.[9]

For these pillars it was found that $S = k\sqrt{R}$, in which S = crushing strength of the coal in pounds per square inch, k = a constant, and R = ratio of lateral dimension to height of pillar. For the pillars tested k = 695. The same form of mathematical expression was found to hold also in tests of four pillars, the height of which was one-half that of the coal bed (lower half of the bed), but for this reduced height the value of k was increased to 915.

### Movement of Mine Roof and Surface Subsidence

During the year this investigation was extended to the Gibson mine of the Hillman Coal & Coke Co.[10] The roof strata over this mine are not as massive as those over mines studied previously, and major breaks over worked-out areas are obtained more easily. There was no evidence of undue convergence of roof and floor or of excessive weight on pillars along rib lines that were kept uniform. Significant convergence was then confined to a narrow belt not more than 70 feet wide adjacent to the goaf area. However, when rib lines became irregular, pillars projecting into the goaf were heavily loaded, as evidenced by excessive convergence.

The underground area studied was beneath a steeply sloping hillside, and retreat of the pillar line was in an uphill direction. Vertical subsidence of the surface was approximately one-half of the thickness of the bed mined and was accompanied initially by lateral movement of as much as 1

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[9] Greenwald, H. P., Howarth, H. C., and Hartmann, Irving, Experiments on the Strength of Small Pillars of Coal in the Pittsburgh Bed: Bureau of Mines Tech. Paper 605, 1939, 22 pp.

[10] Maize, E. R., Thomas, Edward, and Greenwald, H. P., Studies of Roof Movement in Coal Mines. 3. Gibson Mine of the Hillman Coal & Coke Co: Bureau of Mines Rept. of Investigations 3506, 1940, 9 pp.

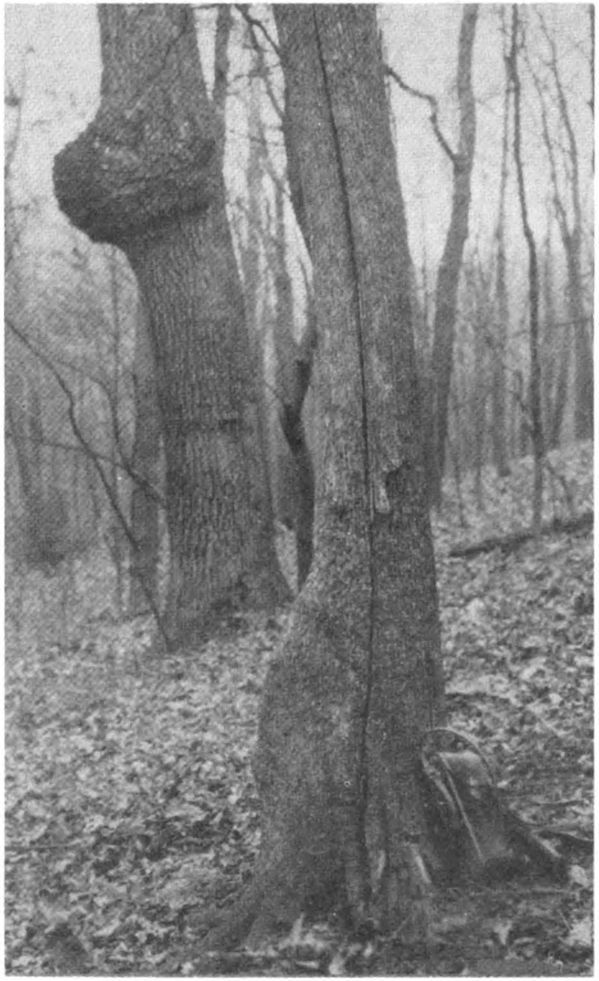

Figure 1.- Tree split by movement of ground over worked-out area, Gibson mine.

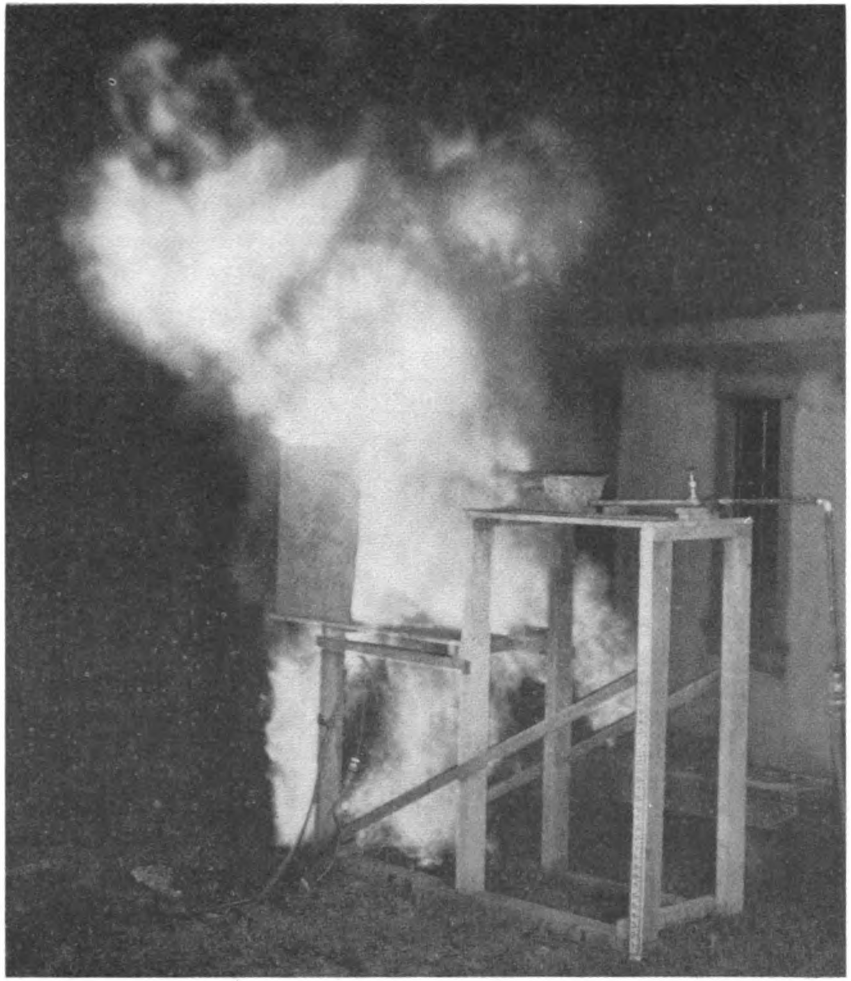

Figure 2.- Ignition of 2 pounds of pulverized coal-tar pitch dust by a 600-watt electric glow coil.

foot down the hill. Long, gaping cracks developed on the surface. Later the lateral movement reversed and in some instances continued beyond the initial location of the point. Uneven subsidence, coupled with lateral movements of this character, are highly destructive to improvements on the surface. The land here is undeveloped, and the only damage of importance was to a gas line that crosses the property. Some idea of the forces involved in these movements may be gathered from figure 1, a photograph of a tree on the line of one of the cracks. The tree was split cleanly into halves.

## Explosibility of Dusts

During the year 94 samples were received for determination of the explosion hazard that might accompany their presence in industry. A large majority comprised coal-mine dusts from Pennsylvania, West Virginia, Colorado, and Oklahoma. Miscellaneous dusts included zinc and urea formaldehyde resins.

A comparison of the results of large-scale tests made in the United States and Great Britain11/ indicates that tests with equipment adopted as standard in one country cannot always be duplicated with different equipment used elsewhere, and that the data obtained in tests in the Experimental Coal Mine carry with them a reasonable factor of safety when applied to commercial mining operations.

### Dusts of Low-volatile Coals

Occurrence during the year of two major explosion disasters caused renewed interest in the results of explosion tests of coal dust made in the Experimental coal mine previously. The relative explosibility of coals low in volatile-matter content was the subject of particular inquiry.12/

These coals contain 8 to 31 percent volatile matter on the dry, mineral-matter-free basis of analysis; in the classification of coal by rank they are designated semianthracite, low-volatile bituminous, and medium-volatile bituminous. On the basis of studies made in the laboratory and Experimental Coal Mine on 22 samples of mine dusts13/ within this range of analysis from Alabama, Pennsylvania, Virginia, West Virginia, and Canada and 67 explosion disasters in low-volatile-coal mines in which 1,829 lives were lost between 1884 and 1938, it is concluded that all such mines should be rock-dusted as thoroughly as though the coal were of relatively high volatile-matter content.

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11/ Greenwald, H. P., Notes on Large-scale Tests of the Explosibility of Coal Dusts Made in the United States and Great Britain: Bureau of Mines Rept. of Investigations 3462, 1939, 9 pp.

12/ Greenwald, H. P., Explosibility of Semianthracite, Low-volatile Bituminous Coals and Medium-volatile Bituminous-coal Dusts: Bureau of Mines Rept. of Investigations 3489, 1940, 11 pp.

13/ "Mine dust" describes a range of size such that 100 percent will pass through a 20-mesh sieve and 20 percent through a 200-mesh sieve. This is a fair average of the most common sizes in operating mines; some finer dusts are found, particularly where friable coals are mined.

## Pulverized Fuel Pitches

An extended investigation of the inflammability and explosibility of pulverized fuel and other pitches produced from coal tar, water-gas tar, and petroleum was completed. Large-scale tests of the explosibility of coal-tar and water-gas tar pitches conducted in the Experimental coal mine were reported last year. During the present year a laboratory study was made of the inflammability of 16 different pitches.[14] The volatile-matter content of these pitches ranged from 45 to 71 percent and the softening temperatures from 200° to 356° F. All the pitches were more inflammable than Pittsburgh coal dust of equal size. With the method of test used it was necessary to have 60 percent inert dust in a mixture with Pittsburgh coal dust to prevent inflammation, whereas with the pitch dust it was necessary to have 65 to 88 percent, the percentage increasing regularly with the volatile content of the pitch.

Tests were made to determine the reduction in oxygen content of the atmosphere required to prevent ignition of the pure pitch dusts. The maximum allowable percentage of oxygen was 12.5 for petroleum pitches, 15 to 17.5 for coal-tar and water-gas-tar pitches (depending on composition), and 17.5 for ordinary pulverized Pittsburgh coal dust. With an especially fine coal dust the maximum content of oxygen allowable was 16.5 percent.

All the pitches were ignited readily by sources of ignition that are found in industrial establishments, such as a glow coil from a radiant heater, a red-hot iron bar, a gas flame, the glowing filament of a broken electric lamp, and the flame of a common safety match. Figure 2 (see p. ) shows the flame resulting from projection of a cloud of 2 pounds of pulverized coal-tar pitch onto a 600-watt electric glow coil.

Despite greater inflammability the precautions necessary to prevent explosions of fuel-pitch dusts in industry are no different from those that have been developed for prevention of explosions of coal dust. These precautions are embodied in a Safety Code for the Installation of Pulverized-fuel Systems approved by the American Standards Association as an American standard on September 5, 1930.

## Prevention of Explosions of Coal Dust by Rock Dusting

Research and experience have shown that maintenance of an adequate amount of rock dust in all underground openings (whether gassy or not) of bituminous and subbituminous coal and lignite mines (anthracite dust does not propagate explosions) is the best way to prevent explosions of coal dust. In rare instances, where all fine particles of coal on the floor, ribs, roof, and timbers are in a muddy condition continuously, rock dusting is not necessary. The requirements for effective rock dusting have been described in a decision of the Mine Safety Board.[15]

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[14] Hartmann, Irving, Howarth, H. C., and Greenwald, H. P., Characteristics of Fuel Pitches and Their Explosibility in Pulverized Form: Bureau of Mines Tech. Paper 617, 1940, 46 pp.

A review of current practice in the application of rock dust to stop or limit explosions of coal dust shows that in mines where good practice is followed the cost of applying limestone or gypsum dust is 0.89 cent per ton of coal mined, or 2.29 cents per linear foot of entry. Probably less than 100 of 6,000 bituminous- and lignitic-coal mines are adequately rock-dusted. In spite of the inadequacy of State laws in this respect, during the past 9 years rock dust is credited with having stopped or limited explosions in 26 of 60 partly rock-dusted mines.[16] The State laws with respect to rock-dusting and watering are reviewed. The effectiveness of the program for preventing explosion disasters is indicated by the fact that the number of deaths from major explosions in the coal mines of the United States decreased from an average of 477 per year for the period 1906-1910 to an average of 43 per year for the period 1933-1938.[17]

## Determination of Incombustible Content of Coal-mine Dusts

Directions for sampling coal-mine dusts in rock-dusted mines and directions for using the Bureau of Mines volumeter method of determining incombustible content of the mine dusts were brought together in one publication.[18] It is desirable that this information be readily available because periodic sampling and analysis of mine dusts is recommended for the control of rock-dusting in coal mines. The volumeter method of analyzing coal-mine dust is rapid, is accurate enough for the control of rock-dusting, and requires no more than ordinary skill for operation; the apparatus can be assembled into a portable outfit.

## Salt as a Substitute for Rock Dust in the Prevention of Dust Explosions in Coal Mines

For some years the Safety in Mines Research Board of Great Britain has been searching for materials more effective than rock dust in preventing propagation of coal-dust explosions in mines. Among the materials tested was common salt, and the Board's tests indicated that it was 5 to 10 times as effective as limestone. This result was so remarkable that it appeared desirable to check it by a series of large-scale tests in the Bureau's Experimental Coal Mine. These tests have been completed and corroborate the British findings qualitatively but not quantitatively. When salt was used in admixture with limestone and coal dust in increments of 5 percent, the first increment was approximately six times as effective as limestone, but the relative effectiveness of the second increment was only 3.5, that of the third was 2.5, and that of the fourth and fifth was only 2.

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[15] Mine Safety Board, Mine Safety Board Decision 32 (Superseding Mine Safety Board Decision 5), Prevention of Coal-dust Explosions by Rock Dusting: Bureau of Mines Inf. Circ. 7109, 1940, 3 pp.

[16] Forbes, J. J., Methods of Rock-dusting American Coal Mines: Bureau of Mines Rept. of Investigations 3465, 1939, 22 pp.

[17] Harrington, D., Formation, Collection, and Treatment of Coal Dust in Mines: Bureau of Mines Inf. Circ. 7089, 1939, 11 pp.

[18] Owings, C. W., Selvig, W. A., and Greenwald, H. P., Methods of Sampling and Analyzing Coal-Mine Dusts for Incombustible Content: Bureau of Mines Inf. Circ. 7113, 1940, 12 pp.

The salt used in these tests was a cheap grade, as more expensive purified salt cannot compete in cost with rock dust now on the market. When ground to requisite fineness the cheap salt was hygroscopic in atmospheres of high humidity. Laboratory tests were made to determine the amount of moisture absorbed by mixtures of salt, limestone, and coal dust containing different proportions of salt; these mixtures were exposed in an atmosphere having temperature and humidity in the range found in many American coal mines. The test was continued 13 days, and it was found that as little as 5 percent salt in a mixture caused it to absorb enough moisture in that time to destroy its effectiveness as dry dust. Also, over the latter part of the test period absorption was at uniform rates in all tests, and there was no indication that it would cease in a reasonable time.

Salt cannot be recommended as a substitute for rock dust unless it is purified or otherwise treated to remove all hygroscopicity when the humidity is 95 to 98 percent at 50° to 60°F. Coal dust and commonly used rock dusts are not hygroscopic under these conditions. It must be determined, also, that salt can be distributed by modern rock-dusting machinery and that it will adhere to roof and ribs as does rock dust. One other point unfavorable to salt is that mixtures in which it was substituted for limestone were considerably darker and reflected illumination much less than did mixtures of limestone and coal dust.19/

## Wetting Agents for Coal-mine Dusts

Mechanization of coal mining has aggravated the problem of control of coal dust near working faces, and questions have been asked as to means of wetting dust more quickly and thoroughly than can be done by use of water alone. Addition of small quantities of any one of a number of wetting agents to the water will accomplish this, but too little is known as yet to justify a statement concerning the relative advantages of the various wetting agents. Present knowledge of the subject has been summarized.20/

## Demonstrations

Two large-scale demonstrations of the explosibility of coal dust were made at the Experimental Coal Mine. Attendance at these was about 310.

## Other Services

The Experimental Coal Mine was of service in the following ways: (1) Furnished materials for and assisted with field demonstrations of the explosibility of coal dust conducted at four places in Pennsylvania and two places in West Virginia; (2) prepared coal dust for use in tests of explosives; (3) prepared places in the mine used in making motion pictures on safe practices; and (4) prepared places in the mine for tests of cap-lamp reflectors and of warning devices for explosive gas.

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19/ Greenwald, H. P., Howarth, H. C., and Hartmann, Irving, Tests of Salt as a Substitute for Rock Dust in the Prevention of Coal-Dust Explosions in Mines: Bureau of Mines Rept. of Investigations 3529, 1940, 16pp.

20/ Hartmann, Irving, and Greenwald, H. P., Use of Wetting Agents for Allaying Coal Dust in Mines: Bureau of Mines Inf. Circ. 7131, 1940, 12pp.

## Underground Transportation of Coal

Where physical conditions in mines favor the installation of mechanical loading devices, one of the most important requirements for efficient operation is an adequate transportation system and supply cars. Rail transportation systems have been studied and analyzed at eight mines.[21] The foundation of a rail-haulage system is well-constructed track properly maintained. The study will be continued to include other means of transporting coal underground.

## Diesel Locomotives

Tests of Diesel engines have shown (1) that ventilation must be provided if the exhaust gases from Diesel engines are discharged in underground working places; (2) that, because of their toxicity, carbon dioxide, carbon monoxide, oxides of nitrogen, and oxides of sulfur (if the fuel contains sulfur) in the exhaust are the most significant constituents in relation to ventilation; and (3) that Diesel engines in underground service should not be operated at fuel-air ratios on the rich side because under these conditions the exhaust contains high concentrations of carbon monoxide and soot.[22] At present Diesel locomotives are not used in American coal mines, but under certain conditions they will afford economical haulage if it is found that they can be used with safety. The fact that they are used abroad does not justify the assumption that they can be used safely in the United States, as conditions in this country require larger engines than are used elsewhere.

Through the courtesy of the Institut National des Mines the Bureau of Mines was enabled to publish a statement on experience in the use of Diesel locomotives in gassy mines in Belgium.[23] The use of Diesel locomotives has been increasing rapidly. Seventeen types have been tested at the Institut. The tests included studies of the operation of locomotives in inflammable atmospheres; of the exhaust gases produced under various operating conditions; of the possibility of back-firing; of the starting facilities; and of other relevant questions.

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[21] Toenges, A. L., and Jones, F. A., Underground Transportation of Coal. Progress Report 1: Bureau of Mines Rept. of Investigations 3519, 1940, 62 pp.

[22] Holtz, John C., Berger, L. B., Elliott, M. A., and Schrenk, H. H., Diesel Engines Underground. 1. Composition of Exhaust Gas from Engines in Proper Mechanical Condition: Bureau of Mines Rept. of Investigations 3508, 1940, 48 pp.

Holtz, John C., and Elliott, M. A., The Significance of Diesel-Exhaust-Gas Analysis: Presented before National Conference of the Oil and Gas Power Division of the Am. Soc. Mech. Eng. at Asbury Park, N. J., June 19-22, 1940.

[23] Breyre, Ad., and Fripiat, J., Diesel Locomotives in Gassy Mine Workings of Belgium: Bureau of Mines Rept. of Investigations 3527, 1940, 17 pp.

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## Mechanization of Coal Mining

In cooperation with the Work Projects Administration, National Research Project on Reemployment Opportunities and Recent Changes in Industrial Techniques, a report was prepared on the mechanization of coal mining.[24] The major change discussed is mechanization of the process of loading coal in mines. The mechanization of loading utilized previous improvements in explosives, undercutting of the bed, and hauling, hoisting, ventilation, screening, and washing, and in turn stimulated improvements in hauling, cutting, drilling, shooting, and mechanical cleaning of coal.

A description of resource conditions shows that the average depth of cover of underground mines is 321 feet; the average thickness of beds mined is more than 5 feet; the average dip of beds mined is 2.49°, and 65 percent of the coal is mined in beds that dip less than 2° and 65 percent of the coal mined underground (that is, excluding strip mines) is from slope or drift mines. The development of strip mining, a result of special resource conditions, is described. However, as only 7 percent of the total bituminous coal mined in the country in 1937 came from strip mines, study of mechanization is focused upon developments in underground mines.

## Inspection of Electrical Mining Equipment

One of the functions of the Bureau of Mines is to determine whether the construction of electrical equipment for mines is such as to minimize hazards connected with operation underground. The hazards to be considered are shock and ignition of gas and coal dust by sparks and flashes.[25] Definite standards have been established as a basis for judging safety of electrical equipment; these are known as schedules and are the result of long experience and study in mines and in the laboratory. The schedule for electric cap lamps was revised in 1939.[26]

When equipment passes the prescribed inspections and tests it is formally approved as "permissible" for use in gassy mines, and the manufacturer is then permitted to mark it with an approval plate that identifies it as having been approved by the Bureau. Lists of permissible equipment are published annually.[27] For the information of mine inspectors, manufacturers, and others interested in safety, publications describing permissible equipment are distributed; thus, a manufacturer wishing to obtain approval of a pump would be able to obtain valuable information from the new paper dealing with pumps.[28]

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[24] Hotchkiss, W. E., Tryon, F. G., Warner, C. K., Plein, L. N., Dake, W. M., Anderson, R. L., Gallagher, J. J., and Schoenfeld, M. H., Mechanization, Employment, and Output Per Man in Bituminous-coal Mining: Work Projects Administration, National Research Project, and Department of the Interior, Bureau of Mines, 2 vol., 1939, 436 pp.

[25] Ilsley, L. C., Investigation of Electrical Equipment, Safety Lamps, and Gas Detectors for Safety: Bureau of Mines Inf. Circ. 7087, 1939, 13 pp.

[26] Bureau of Mines, Permissible Electric Cap Lamps - Procedure in Testing; Fees Charged; and Requirements for Approval: Sched. 6D, approved August 26, 1939, 7 pp.

[27] Ilsley, L. C., List of Permissible Mine Equipment Approved to January 1, 1940: Bureau of Mines Inf. Circ. 7110, 1940, 27 pp.

## Inspection of Mechanical Mining Equipment

Safety and economy in the use of hoisting rope are based upon good design of hoisting system, intelligent maintenance, thorough inspection, accurate records, judicial interpretation of inspections in relation to records, and emphasis on safety rather than maximum period of use of rope.[29] Samples of discarded hoisting ropes are being collected for testing and study.

## Testing of Explosives for Coal Mines

The Explosives Division made physical tests, analyses, and other chemical tests of explosives and blasting devices to establish their permissibility for use in coal mines. The performance requirements, prescribed conditions of use, and fees for testing explosives and blasting devices are presented in Schedule 1C.[30] Complete lists of permissible explosives and blasting devices are published annually.[31] On June 30, 1940, the lists contained the brand names of 195 permissible explosives and nine permissible blasting devices. On June 30, 1939, the corresponding lists showed 186 permissible explosives and nine permissible blasting devices. The Bureau regards these explosives and blasting devices as safe for use in coal mines under certain prescribed conditions.

## Cushioned Blasting

Cushioned blasting is designed to save the energy usually lost in excessive shattering and in this way to effect economies and to produce greater proportions of desirable lump coal. A review of developments in cushioned blasting, together with results of orienting gallery tests, emphasizes the need for experimental studies of the methods recommended, that is, the use of stemming devices, if they are to be applied safely.[32] The gallery tests disclosed, among other facts, marked effects on the risk of ignition of firedamp by blown-out shots caused by two devices proposed for use as stemming.

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[28] Ilsley, L. C., Gleim, E. J., and Brunot, H. B., Permissible Electrically Operated Pumps: Bureau of Mines Rept. of Investigations 3497, 1940, 23 pp.

[29] Ilsley, L. C., and Mosier, McHenry, Inspection and Maintenance of Mine Hoisting Ropes: Bureau of Mines Tech. Paper 602, 1939, 27 pp.

[30] Bureau of Mines, Procedure for Applying for Tests Made on All Explosives and Blasting Devices by the Explosives Division of the Bureau of Mines - Prescribed Conditions and Requirements for Permissibility When Used in Coal Mines and Schedule of Fees for the Tests: Sched. 1C, 1939, 13 pp.

[31] Tiffany, J. E., and Gaugler, Z. C., Active List of Permissible Explosives and Blasting Devices Approved Prior to June 30, 1939: Bureau of Mines Rept. of Investigations 3471, 1939, 25 pp.

[32] Denues, A. R. T., Cushioned Blasting. 1. Orienting Studies: Bureau of Mines Rept. of Investigations 3510, 1940, 23 pp.

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## Ignition of Firedamp by Explosives

Continuing the study of the igniting action of the various emissions from a detonating explosive, a report[33] prepared for presentation to the Fifth International Conference of Directors of Mine Safety Research, later postponed, indicates that the conditions governing the distribution of energy from the hot gases and perhaps the shock waves of the mixture of firedamp and air is probably more important than the energy communicated to that mixture by the incendive particles, and that hydrodynamic conditions of flow and mixing probably explain some of the anomalies noted in gallery tests. Another report[34] for the same conference suggested the hypothesis that the ignition hazard is produced by the projection of solid particles from the explosive into the mixture of firedamp and air, giving rise to a fold or pocket type of contact between the gaseous products of detonation and the mixture of firedamp and air. The hypothesis was developed to explain the varied results found by different workers both for borehole shots and the detonation of freely suspended cartridges.

Through the courtesy of the Comité Central des Houillères the Bureau was enabled to publish a description of experiments conducted in France.[35] Application of the methods described to balance mixtures of gelatinized nitroglycerin, ammonium nitrate, wood pulp, and inert salt (sodium and potassium chloride) has led to the development of explosives that, when fired in a shot hole, have no effect on gaseous mixtures still are strong enough to be practical.

## Methods for Determining Poisonous Gases from Explosives

Factors that affect testing-station results have been studied and the oxygen balances of industrial explosives (necessary for continued research) have been determined. Experiments gave nitrogen balances that agree within approximately 3 percent and indicate that the nitrogen balance is the only satisfactory check on the results when only the gaseous products are considered. It is indicated that the oxygen balance is affected by materials in the detonator and that the carbon balance is affected by absorption of carbon dioxide by alkaline residue from the explosive.[36]

## Transportation of Explosives

The construction and use of rugged, nonconducting cars to transport explosives in mines are recommended to increase safety.[37]

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[33] Gerhard, S. L., Holtz, J. C., and Huff, Wilbert J., Recent Research by the Bureau of Mines on the Ignition of Firedamp by Explosives: Bureau of Mines Rept. of Investigations 3464, 1939, 12 pp.

[34] Lewis, Bernard, and von Elbe, Guenther, Ignition of Firedamp by Explosives: Bureau of Mines Rept. of Investigations 3463, 1939, 11 pp.

[35] Audibert, E., An Experimental Study of the Ignition of Firedamp-Air Mixtures by Explosives: Bureau of Mines Rept. of Investigations 3518, 1940, 6 pp.

[36] Holtz, John C., Gaseous Products from Explosives. 1. Some Factors Affecting Test Results: Bureau of Mines Rept. of Investigations 3507, 1940, 14 pp.

[37] Owings, C. W., Cars for Transporting Explosives: Bureau of Mines Inf. Circ. 7115, 1940, 6 pp.

## Ventilation of Mines

An initial series of tests on fan-pipe ventilation was completed, and the results are embodied in a report 38/ about to be published. It was found that the changes in velocity and distribution of velocity with distance from discharge follow definite laws by the aid of which the design of such lines can be put on a technical basis that should result in improvement of this type of ventilation.

Means provided to control temperature of ventilating air have been installed at a number of mines to reduce expansion and contraction of roof due to changes of temperature and thereby to reduce or eliminate falls of roof. Air washers or coolers installed at five bituminous coal mines are described in a recent publication. 39/

## Respiratory Protective Devices

To promote the development of safe, satisfactory, and reliable respiratory protective devices the Bureau has established schedules of minimum requirements for oxygen breathing apparatus, gas masks, supplied-air respirators (hose masks, airline respirators, and abrasive blasting helmets, hoods, or masks), and mechanical filter respirators. Manufacturers may submit such equipment to the Bureau for approval under the requirements of these schedules. The requirements, methods of testing, and design and operating principles of approved equipment have been described. 40/

## Fires in Anthracite Mines

Laboratory work was continued on the causes, behavior, and control of fires in anthracite mines. 41/ The amount of oxidation or heating that takes place in stored coal can be estimated from the analysis of anthracite. 42/ It has been discovered that in some mines there are bacteria that have the property of oxidizing carbon monoxide and hydrogen to carbon dioxide and water vapor. 43/ In view of the fact that these gases and their relationships with other gases in the atmosphere created by fires in mines have been used in the past to determine when fires have been extinguished and to estimate the activity of fires in mines it is important that the presence or absence of such bacteria be known before an estimate is made of the status of fires.

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38/ McElroy, G. E., Air Flow at Discharge of Fan Pipe Lines in Mines. Part 1. 10-inch Line in Development End: Bureau of Mines Rept. of Investigations 3531, 1940, 14 pp.

39/ Herbert, C. A., Cooling Mine Air During Summer Months to Prevent Roof Falls: Bureau of Mines Inf. Circ. 7098, 1940, 14 pp.

40/ Schrenk, H. H., Testing and Design of Respiratory Protective Devices: Bureau of Mines Inf. Circ. 7086, 1939, 11 pp.

41/ Jones, G. W., and Scott, G. S., Chemical Considerations Relating to Fires in Anthracite Refuse: Bureau of Mines Rept. of Investigations 3468, 1939, 13 pp.

42/ Scott, G. S., and Jones, G. W., Phenomena Observed During the Prolonged Oxidation of Anthracite: Bureau of Mines Rept. of Investigations 3504, 1940, 8 pp.

43/ Jones, G. W., and Scott, G. S., Oxidation of Carbon Monoxide and Hydrogen by Bacteria: Bureau of Mines Rept. of Investigations 3466, 1939, 10 pp.

Frequent inspections of surface waste piles and recording of subsurface temperatures with analyzing of the gases from a few feet below the surface have value in preventing the firing of refuse banks or in discovering incipient fires. These data can and should be obtained by drilling holes a few feet in depth wherever evidence of heating is noted, as, for example, by the presence of steam or smoke or the melting of snow.44/

## PREPARATION OF COAL

### Coal-washing Problems in Alabama

The washability of representative samples of coal from the America and the Pratt coal beds in the vicinity of Gorgas, Ala., has been studied.45/ These studies are based principally upon screen sizing and sink-and-float fractionations made in the laboratory. They indicate that the America coal can be washed efficiently to reduce the ash from 16.8 to 9.1 percent, moisture-free, and the ash of the Pratt coal can be reduced from 10.3 to 7.6 percent, moisture-free. The Pratt and the America beds are mined extensively near Birmingham but have not been developed extensively near Gorgas to the northwest. It is evident that the cleaning of the America- and the Pratt-bed coals will be much more difficult near Gorgas than in the proximity of Birmingham.

### Drainage Characteristics

In the study of the factors that influence the drainage of Alabama coals after washing a laboratory drainage test has been developed from which fairly accurate predictions can be made as to the amount and rate of drainage that may be expected. The results of the laboratory tests with actual railroad-car drainage have been correlated by experimental work at the mines during the loading period and by sampling during unloading of railroad cars. The laboratory tests have been made on a number of samples of washed coal from different beds in the Warrior and Cahaba fields of Alabama. They show that relative surface is the principal factor that determines the rate of drainage. The only other factor of any considerable importance is distribution of sizes.

### Flotation of Coal from Washery Slurry

The study of methods to recover coal from slurry at coal-cleaning plants in Alabama has resulted in the installation of a pilot flotation plant that is treating about 150 gallons of slurry a minute. The wet system of coal cleaning used in Alabama requires that a considerable amount of water be removed from the washeries continuously and wasted to prevent the solids from accumulating in the circulating water to such an extent as to interfere with the cleaning operation. The water or "slurry" thus removed carries in suspension solids consisting mainly of fine coal with an admixture of varying amounts of clay and other impurities.

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44/ Leitch, R. D., Some Information on Extinguishing an Anthracite Refuse-bank Fire near Mahanoy City, Pa.: Bureau of Mines Inf. Circ. 7104, 1940, 16 pp.

45/ Gandrud, B. W., and Coe, G. D., Washability Studies of the America and Pratt Coal Beds at Gorgas, Ala.: Bureau of Mines Rept. of Investigations 3458, 1939, 12 pp.

The work is still in the experimental stage until it can be determined whether or not the recovered coal can be added to the washed slack without detrimental effects. The effect it may have on both coking coal and steam coal must be considered, as part of the slack coal is shipped to byproduct plants and the remainder to power plants.

The coal recovered by the pilot plant differs from the other coal, not only in fineness but in chemical characteristics as well, owing to its abnormally high content of fusain - approximately 50 percent of the total product recovered in the flotation plant. This segregation results from the crumbly nature of the fusain. The effect of adding this high-fusain product to the coking coal can be determined only by actual tests in ovens. In steam coal it is probable that it will retard the drainage of the slack in railroad cars during transit, thus affecting slightly the moisture content of the delivered coal. Actual tests in steam plants will be necessary to determine whether the addition of the fine flotation product to the steam coal will increase clinkering.

## Flocculation as an Aid in the Clarification of Coal-washery Water

The water, fine coal, and impurities ordinarily are removed from the water used for washing by means of settling tanks. Settling and classification may be hastened markedly (thereby greatly increasing the capacity of clarification equipment) by the addition of substances to the washery water that cause the fine particles in suspension to agglomerate and thus settle more rapidly. An investigation[46] showed that starchy materials, such as potato starch, wheat flour, and cornstarches, are effective as flocculants of coal but usually show a short range of reagent concentration in which they have maximum effectiveness. Electrolytes are effective flocculants over a wider range, but the concentration necessary to produce good flocculation is much higher. Electrolytes are more effective than starches in flocculating shale, but some of the electrolytes might be objectionable in use. Flocculation probably is not necessary unless the slurry contains a considerable amount of material smaller than 200-mesh. Flocculated-coal slurries filter much more rapidly than unflocculated ones.

## Utilization of Coal-mine Refuse

The high-coal fraction of a coal-mine waste has been made successfully, on a laboratory scale, into a decolorizing carbon having an activity for color removal from sugars comparable to the better grades of commercial color carbons. Moreover, an activated carbon for water purification has been made from this same fraction with an activity for odor and taste removal from water equal to the better grades of water carbons, as evaluated by the phenol-adsorption test.

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[46] Yancey, H. F., Zane, R. E., Wood, W., and Cannarella, J. T. H., Flocculation as an Aid in the Clarification of Coal Washery Water: Bureau of Mines Rept. of Investigations 3494, 1939, 13 pp.

An extensive series of tests using zinc chloride as the chemical activating agent was completed. The data obtained from these tests show the conditions necessary for the preparation of activated carbon from coal refuse by the zinc chloride method. This method produced a more active carbon than was previously obtained by steam activation. The best carbon had a phenol number of 18, as compared with 23, the minimum number by the steam process. The lower the phenol number, the greater the activity of the carbon, and a phenol number of 30 is specified as the upper limit for a good commercial carbon. Activation by the use of chlorine was tried, also, but did not appear promising and was not studied further. All of the carbons were activated for the removal of objectionable tastes and odors from municipal water supplies.

Activation of coal-mine refuse for water-softening purposes was not satisfactory because the exchange capacities were low and the loss of fines was high, owing to disintegration of the granular material.

### Coal Refuse as a Soil Conditioner

Because of its dark color, coal refuse may be used as a darkening agent on light-color soils. Field experiments have been completed in which the darkening of a light-color soil with coal refuse prevented the burning of tips of gladioli by reflected sunshine.[47]

### Drying Subbituminous Coal and Lignite by High-pressure Steam

During the last 2 years the University of North Dakota, in cooperation with the Bureau of Mines, has made technical investigations and economic studies on the Fleissner process for drying coal with high-pressure steam. These studies show that American high-moisture coals can be dried to improve their gross heating value by 30 to 50 percent.

The investigation has included studies of nine typical high-moisture coals. Approximately 50 tons of coal has been dried under many different conditions to determine the effects of steam pressure, size of coal, and length of heating cycle on the properties of the dried residues.

All the high-moisture coals can be dried with high-pressure steam; however, subbituminous coals disintegrate slightly more than lignites, but less dust is formed. The amount of water expelled from the coal is 10 to 40 percent of the total moisture. Because the moisture is removed as liquid less heat is required for drying by steam than for drying by flue gas. The data indicate that under American conditions the process is more suitable for small than for large sizes of coal.

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47/ Broderick, S. J., Darkening Light-color Soils with Coal-mine Waste: Bureau of Mines Rept. of Investigations 3516, 1940, 6 pp.

## Pulverized Coal and Its Preparation

This study was undertaken to determine the energy consumed in pulverizing different coals. The first step was to design and construct a device capable of recording accurately only that portion of the total energy input consumed in actual pulverizing. The channel-roller pulverizer and pendulum-balanced force recorder were conceived and a small laboratory model built for test purposes. This was the status of the investigation at the end of 1939. During the past year numerous tests were conducted with this machine, and several changes were made in the original design until it has emerged as a machine suited to the purpose.

The next step was the construction of a similar pulverizer capable of pulverizing particles as coarse as 3/4 inch. It was then attempted to adapt the machine to continuous operation. Inasmuch as most commercial pulverizers are air-swept the air-swept principle was accomplished by suspending the inlet of an air separator over the channel. Suction applied through a cyclone connected to the air separator withdraws most of the coal of near pulverized-coal size from the channel and into the separator. The air separator makes a separation at about 150-mesh, the minus-150-mesh material being conveyed by suction from the separator to a cyclone, where it is settled and recovered. The plus-150-mesh fraction is discharged from the air separator directly to the channel for further reduction. A vibrating feeder attached to the pulverizer and controlled by the force recorder feeds minus-3/4-inch coal at the same rate at which the minus-150-mesh product is removed from the circuit. Thus, a definite amount of coal is maintained in the channel of the pulverizer.

Accurate sizing analysis of the pulverized product is essential in this work. This has been achieved by use of the Andreason pipette, accurate for sizes from 400-mesh down to 4 microns. However, the method is time-consuming; therefore, a new type of sedimentation balance has been built, which appears to be as accurate as the Andreason apparatus and requires only about half as long to make a determination.

Another phase of the investigation is accurate sampling of the pulverized product from commercial installations. The usual commercial practice is to convey the pulverized coal directly to the furnace by air stream, through ducts. This system necessitates sampling the product in the ducts. Tests of the method commonly employed for this type of sampling have proved it to be unreliable. No method has yet been investigated to the extent that it can be said to be entirely satisfactory.

Contrary to general belief the ash-bearing constituents are not always most resistant to crushing, as was shown in tests of coal constituents - that is, vitrain, clarain, durain, and fusain - from the Southern Illinois field. The net power consumed in crushing the constituents from minus 20-mesh to minus 150-mesh, with their ash content are given in the following table:

| Coal constituent | Fusain | Vitrain | Clarain | Durain |
|---|---|---|---|---|
| Net horsepower-hours per ton of minus-150-mesh product... | 1.8 | 3.8 | 5.1 | 13.6 |
| Ash, percent....... | 15.6 | 2.2 | 8.3 | 5.2 |

It is shown that the durain, the hardest constituent, contains less ash than the clarain. Although comparison of the values for fusain with any of the others is even more startling it has been recognized that fusain is the most easily crushed constituent, in spite of its relatively large percentage of ash. Tests of washed coal from a mine in the northern part of the Warrior field, Alabama, showed this same characteristic; that is, the low-specific gravity material and relatively low ash required 20 percent more power for pulverization than did the higher-specific gravity and relatively higher-ash material.

## UTILIZATION OF COAL

### Combustion

### Fuel-economy Service

The fuel-economy service is a consulting service rendered to other agencies of the Government on the selection and use of fuels and equipment for burning fuels. In connection with the maintenance of steam boilers service is given with respect to correct conditioning of boiler feedwater.

Comparisons of operating costs with different fuels were made for large and small plants throughout the country, and the appropriate types of equipment were recommended for economical utilization of the selected fuels under the conditions and demands existing at the plants. After installation of equipment acceptance tests were made at the larger plants and at plants where equipment of new types was installed. After tests and inspections of plants operating methods were recommended, and forms were prepared for recording operations and costs.

Surveys of steam and power requirements were made for Government institutions, and programs were prepared for enlarging plants to meet the needs of future growth.

Specifications to insure the delivery of suitable coals, coke, and fuel oil were prepared for numerous individual plants, and subsequently bids were analyzed.

Boiler Feed-water Conditioning. - Water analyses and resulting recommendations were made for 249 samples from plants in the District of Columbia; 187 from the Justice Department; 110 from the War Department; 148 from the U. S. Housing Authority; 414 from the Office of Indian Affairs; 82 from the U. S. Public Health Service; 109 from the Department of Agriculture; 51 from the Post Office Department; 6 from the Veterans Administration; and 4 from the Navy Department. Report was made on the analysis of 14 boiler compounds and 24 scales and sludges for various activities. A copper sulfate treatment was started at a turbine-plant cooling pond to control algal growth.

The Government had found it necessary to use a patent chemical for preventing priming in the smaller heating systems such as in the schools. The compound used cost $1 a pound, and about 600 pounds were used a year. This compound was examined and appeared to be ground phosphate rock. Laboratory experiments were made on ground rock, and similar results to the patent compound were indicated; therefore, substitution of ordinary ground phosphate rock was advised. The ground rock is proving completely satisfactory and is resulting in the saving of about $600 a year.

Smoke Abatement. - Consulting service was given to municipalities and Government plants on the abatement of smoke and fly ash. In many plants emission of smoke can be reduced or eliminated by simple changes in operation or by the addition of inexpensive auxiliary equipment, and the change usually is accompanied by saving of fuel and other reductions of cost of operation.48/

Utilization of Fly Ash. - A new plan for reburning fly ash high in combustible, as recovered from fly-ash collectors, was suggested to engineers of a large public utility. This plan involves use of a nozzle-type spreader stoker to spread the fly ash over the fuel bed of an underfeed stoker. A spreader was installed and used so successfully that the company expects to install them in 14 other furnaces.

## Determination of Combustible in Fly Ash

Fly ash is the finely divided particles of ash carried from a furnace in the gas stream. The loss of fly ash on ignition is often determined to estimate unburned carbon or combustible matter present. Errors may occur because a standard method is not in general use and because the mineral matter of the fly ash may change in weight during ignition. These factors were investigated on three samples having a carbon content ranging from 3.4 to 15.1 percent, as determined by ultimate analysis. Loss on ignition was determined at 750°C. by the A.S.T.M. standard method of determining ash of coal and coke.. On ignition changes in the mineral matter of the fly ash were found to be slight, except for loss of water that is chemically combined in some of the mineral matter. In the standard procedure for ignition loss this combined water is driven off and included with the combustible matter. The tests show that the difference between 100 and the sum of ash and combined water may be considered to be combustible matter.

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48/ Barkley, J. F., The Importance and Attainment of Smokeless Boiler Plant Operation: Heating, Piping and Air Conditioning, vol. 11, December 1939, pp. 691-693.

## Removal of Ash as Molten Slag from Pulverized-coal Furnaces

Investigations have been conducted for several years concerning properties of ash of coals at high temperatures. The work originated with studies related to the molten ash of slag-tap furnaces. Before the introduction of this type of furnace rarely was all the ash completely melted, and there was less need for data on the properties of molten ash; clinkers usually were a mixture of partly melted material, although large blocks of completely fused slag were found in the refuse of underfeed stokers. If the slagging-type gas producer had come into general use, need for data on molten slags would have been felt earlier.

There has been close contact with operation in boiler plants during this investigation, and its course has been influenced by samples collected and by observations of difficulties in operation that occur. Thus, the need for certain data was forseen before operators realized they would require them.

Laboratory studies. - The "feel" method was adopted as a measure of relative fluidity to supplement the cone-fusion temperatures. Much was learned by it, but, as it did not give numerical values, it was not the final answer.

Finally, the decision was made to develop a method of measuring the viscosity in spite of the predictable high cost of this type of investigation. The development was begun in November 1938, and by August 1939 studies had been made of a few slags having a wide range of composition.

These tests cleared much of the fog that had surrounded this subject and clarified ideas on methods of attack for further work. Important principles established by the tests were:

1. Within only a narrow range of composition do slags act as true glasses, and in all others components crystallize out, thus establishing a liquidus point.

2. Slags having the same liquidus temperature do not necessarily have the same viscosity at temperatures above the liquidus, and they may differ widely.

3. Decreasing the ferric percentage of a slag lowers its liquidus temperature but does not materially change the viscosity at temperatures at which the slag is a fluid.

The enlarged viewpoint resulting from these tests was a milestone for the investigation.[49]

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[49] Nicholls, P., and Reid, W. T., Viscosity of Coal-ash Slags: Trans. Am. Soc. Mech. Eng., vol. 62, 1940 pp. 141-153.

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Little further work was done on determinations of viscosity of slags because the conclusions were that the study should be enlarged to include all properties that might be measurable. Viscosity determinations are too expensive and difficult to be done for individual coals in commercial laboratories. The solution was that determinations should cover the whole field of composition of coal ash and that the commercial procedure would be to make a chemical analysis of the ash.[50] The plan for future work on the problem is given in the following table; other phases must be followed, particularly those that will maintain contact with operations in the field.

Properties of Coal Ash to be Determined

1. Chemical analyses:
    a. Of the ash.
    b. Determination of the iron forms in the slags of the tests of 3a and 3b.
2. A.S.T.M. cone fusion test of:
    a. The ash as prepared from the coal.
    b. The ash after complete fusion.

3. Absolute viscosity at temperatures above that of the liquidus.
    a. In an atmosphere of air; that is, with the highest ferric percentage possible in service.
    b. With one or more imposed lower ferric percentages; each of these requires a completely new test.

4. Apparent viscosity at temperatures below that of the liquidus:
    a. Same as 3a.
    b. Same as 3b.

5. Surface tension as related to temperature:
    a. Same as 3a.
    b. Same as 3b.

6. Density:
    a. Of solid slag.
    b. Of molten slag.

7. Adhesion of slag to surfaces.

Surface tension. - Apparatus was designed for measuring the surface tension of molten coal-ash slags utilizing the method in which a bubble is blown with inert gas at the tip of a calibrated platinum tube barely touching the surface of the slag. The static pressure just insufficient to cause the bubble to burst is a measure of the surface tension.

Density of slags. - The density of slags at high temperatures is to be measured by an apparatus that operates on the principle of displacement of slag and consequent change in weight when the platinum bob ordinarily used for viscosity determinations is immersed in the slag.

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[50] Nicholls, P., and Reid, W. T., Status of Knowledge on Properties of Coal Ash: Proc. 26th Fuel Eng. Conf. Appalachian Coals, Inc., June 21, 1940 (mimeographed).

Apparent viscosity. - The measurement that will present most difficulties is what may be termed the apparent viscosity at temperatures below that of the liquidus. The force required to produce a given deformation of a slag containing solid phase usually will depend on the conditions of the test, and thus numerical values will be arbitrary. The quantity, and often nature, of crystals for a given temperature will depend on previous history, time, and the dimensions of the test apparatus.

It was desirable that all tests of one slag could be made in sequence with the one melting in the crucible. The oscillating method is not suited, because the applied forces to overcome slag resistance are so small. The method adopted was that of rotating the bob. A new viscometer based on the Margules or rotating-cylinder type was designed and constructed. This instrument indicates viscosity by measuring the energy required to rotate the platinum bob immersed in slag contained in a platinum or ceramic crucible. The energy required to produce rotation is furnished by a small, variable-speed motor and is measured by determining the torque required for a given speed of rotation; the torque is measured by the twist produced in a length of calibrated piano wire in the driving system. The twist in the wire was measured successfully with an electronic contact-indicating device sensitive to extremely short duration of contact, as is required when the bob is rotating at maximum speed (20). This instrument includes a number of novel features and, in spite of delicate construction required, is highly accurate.

Figure 3 is a photograph of the driving head and motor. The tripod is needed to align the suspension and to support the parts for measuring the angle of torque and for the safety features. This method of measuring apparent viscosity has an advantage over determinations like cone fusions in that (a) numerical values are obtained, (b) the measurements on one slag can be continued indefinitely and the applied conditions changed, (c) more than one set of applied conditions can be standardized.

Temperature controller. - A modification of the temperature controller was built, with its sensitivity increased about five times. It was described in a paper, An Electronic-contacting Galvanometer for Temperature Control, presented at the Temperature Symposium of the American Institute of Physics in November 1939.

Crucibles. - Ceramic crucibles suitable for melting slags of high flux content were tested in an attempt to obtain materials suitable for use in the viscometer. Two crucible bodies of domestic manufacture were found that were considered to be nearly satisfactory, and it is hoped that greater skill by the manufacturer will make them entirely satisfactory. The bodies are purified chromite and sintered alumina.

## Field Studies

Actions in the slag beds of powdered-coal furnaces were observed at a public-utility plant, and further information was gained relative to the formation of deposits of infusible slag and the production of metallic iron (or alloys consisting principally of iron) in beds of slag. One of the

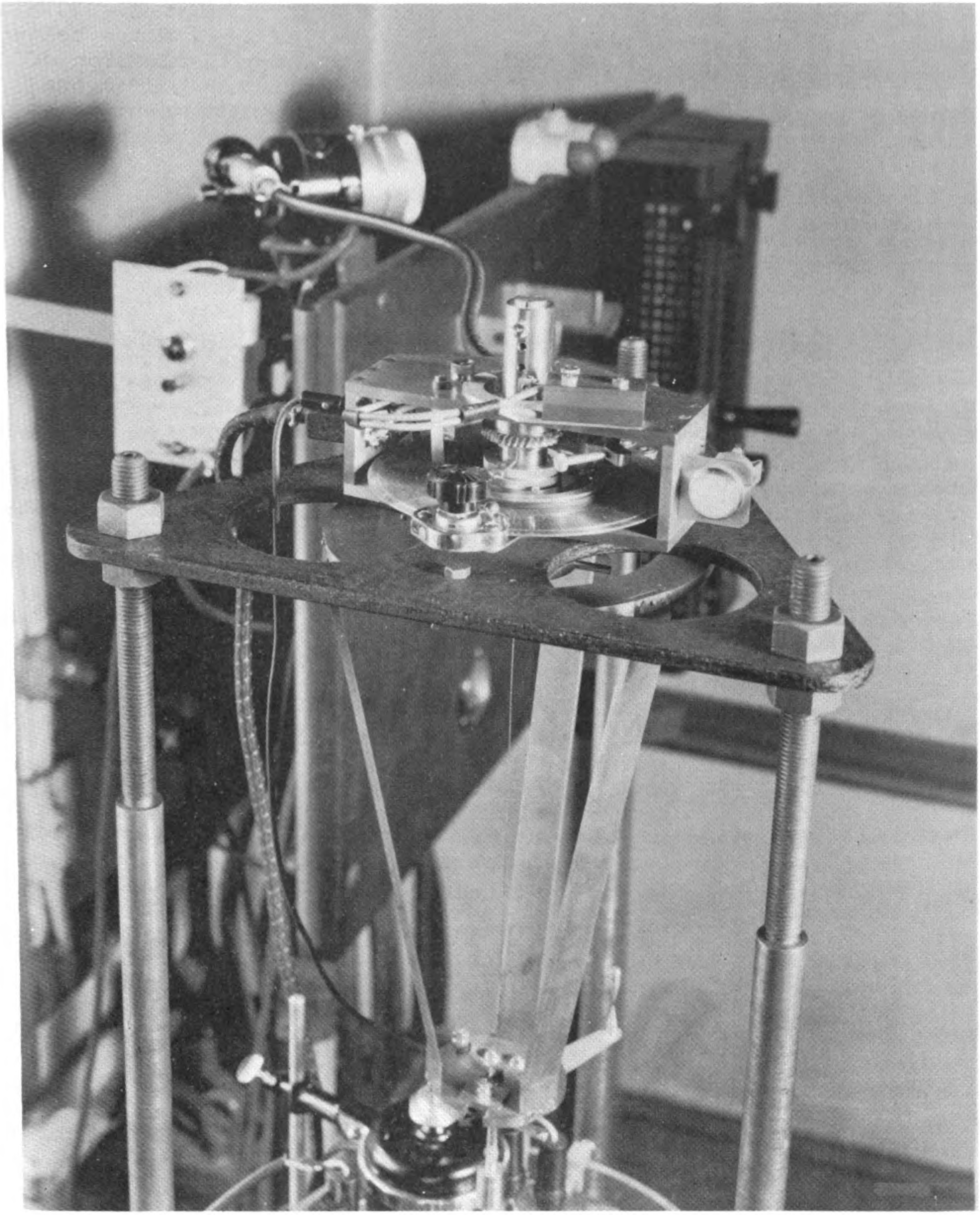

Figure 3.- Rotating head of viscometer for coal-ash slags.

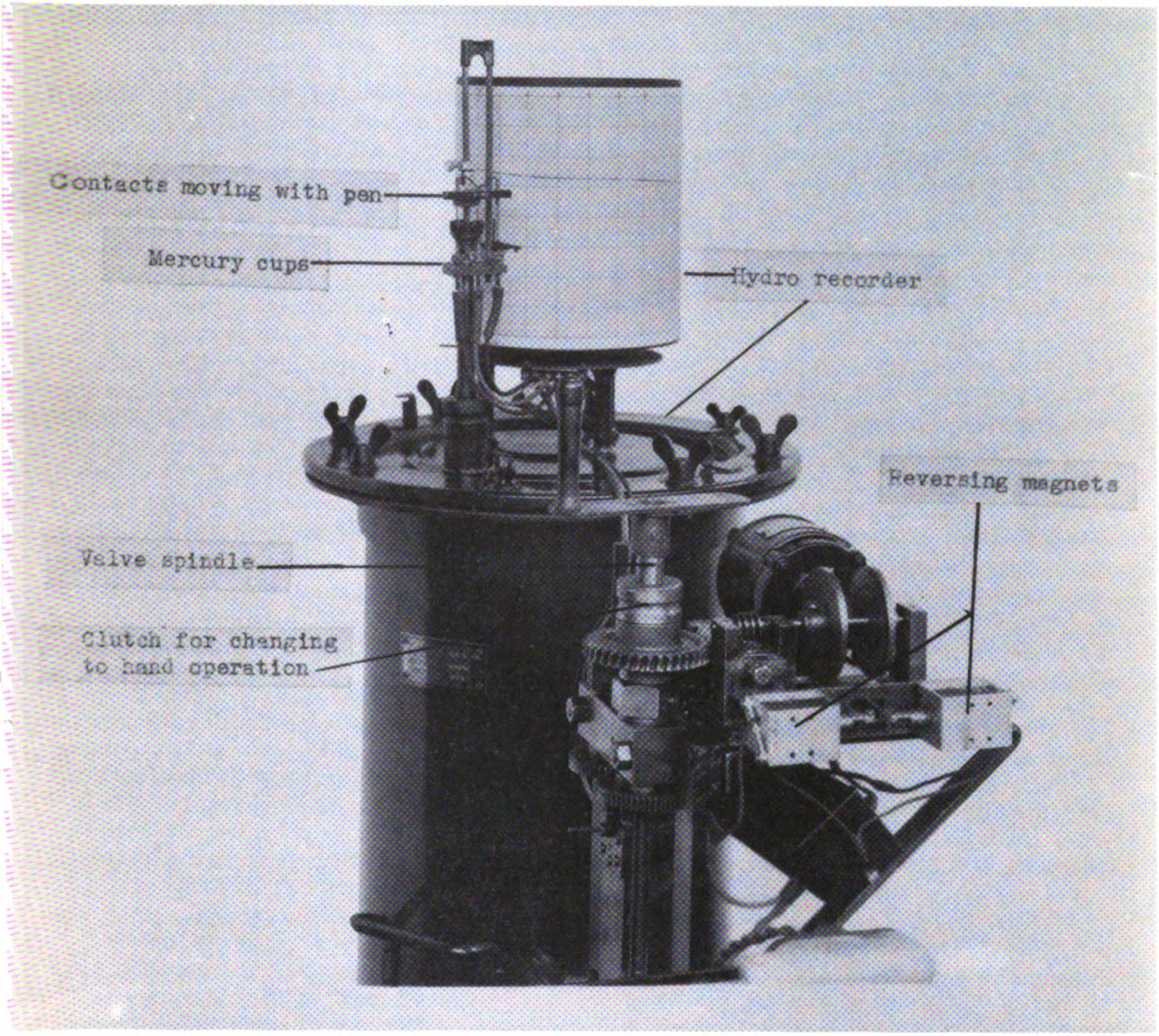

Figure 4.- Device operating recording draft gage to maintain constant drop of pressure across an orifice.

principal facts discovered is that reduction of silicates to silicon can occur in slag beds, and that such reduction can be serious in modifying both the properties of the iron deposit and of the remaining slag.

## Burning Solid Fuels on Traveling Grates

The apparatus that has been described has met expectations.[51] All tests are made with a constant rate of air supply, which means a constant drop in pressure across an orifice in the air line. Figure 4 is a photograph of a device developed to do this regulating automatically. It consists of a constantly running motor that raises and lowers the damper through a gearing, the direction of rotation of which is reversed by magnets controlled from the position of the pen of a recording draft gage.

The tests have been restricted to high-temperature cokes and to anthracites. These noncaking fuels are favorable to studies of principles, and therefore more tests have been made than will be warranted with caking coals. The variations studied for one fuel have been limited to size of fuel, rate of supplying, primary air, and ignition temperature, with a few tests using secondary air with small-size anthracite to help the burning of pieces in suspension; moreover, some tests with moisture added to the fuel. It is proposed to study some of these same fuels with varying amounts of preheat. Even with this limited number of variables, many tests would be required to cover the full ranges of all variables, and some restrictions are necessary. Not enough tests have been made to permit publication of results.

## Performance of Subbituminous Coal in a Domestic Stoker

Through the cooperation of the Northern Colorado Coals, Inc., the Bureau of Mines studied the utilization of subbituminous coal in a modern domestic stoker. The object of the investigation was to determine efficient methods of operation and to study the relationship of sizes and ranges of sizes to performance in small stokers and to study changes in the design of retort to permit improved combustion of subbituminous coal and lignite. A warm-air furnace with a steel firebox was used in the tests, and the stoker, with a special floating firebox, was mounted on scales.

Two sizes of coal - modified pea and 2-1/2-inch slack - were burned at various rates. It was observed that in the retort supplied with the stoker there was little difference in operation between the two sizes. The slack was dustier than the modified pea, but the attention required for satisfactory operation of the furnace was about the same for each size. Although slightly more power was required to burn the slack and the pressure in the retort was higher, combustion was as good as was obtained with modified pea coal. The similarity of combustion probably was due to the crushing action of the worm on the pea coal, which was reduced to almost the same size as the slack.

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[51] Fieldner, A. C., and Brewer, R. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1939: Bureau of Mines Inf. Circ. 7105, 1940, 59 pp.

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## Coke and Gas Making

Recent progress in the making of gas and coke by high- and low-temperature carbonization as well as in the briquetting and packaging fuel and the hydrogenation and liquefaction of coal has been summarized in a review prepared for the Coal Division of the American Institute of Mining and Metallurgical Engineers.52/ Although research has continued and improvements have been made in existing plants industrial conditions have not favored construction of new plants.

## Survey of Carbonizing Properties of American Coals

Technical papers published during the year53/ describe the carbonizing properties and petrographic composition of four representative coals. The relationship of yield and quality of products of carbonization to rank of coal and temperature of carbonization also was described.54/

The carbonizing properties of five coals were determined during the year by the methods developed earlier in the survey.55/ Coals 60 and 64 are medium-volatile bituminous and coals 61, 62, and 63 are high-volatile A bituminous. The medium-volatile coals were blended with high-volatile A bituminous coal from the Pittsburgh bed, and the high-volatile coals were blended with two low-volatile coals from the Pocahontas No. 3 and No. 4 beds.

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52/ Fieldner, A. C., Processing and Carbonization: Min. and Met., vol. 21, 1940, pp 33-35.

53/ Fieldner, A. C., Davis, J. D., Reynolds, D. A., Selvig, W. A., Sprunk, G. C., and Auvil, H. S., Carbonizing Properties and Petrographic Composition of High Splint-bed Coal from Closplint Mine, Closplint, Harlan County, Ky.: Bureau of Mines Tech. Paper 599, 1939, 38 pp.

Fieldner, A. C., Davis, J. D., Selvig, W. A., Brewer, R. E., Holmes, C.R., Reynolds, D. A., and Sprunk, G. C., Carbonizing Properties and Petrographic Composition of Sewell-bed Coal from Wyoming Mine, Wyoming County, W. Va., and the Effect of Blending this Coal with Alma-bed Coal: Bureau of Mines Tech. Paper 601, 1939, 45 pp.

Fieldner, A. C., Davis, J. D., Reynolds, D. A., Schmidt, L. D., Brewer, R. E., Sprunk, G. C., and Holmes, C. R., Carbonizing Properties and Petrographic Composition of Pocahontas No. 3-bed Coal from Buckeye No. 3 Mine, Wyoming County, W. Va., and of Pocahontas No. 4-bed Coal from No. 4 Mine, Raleigh County, W. Va.: Bureau of Mines Tech. Paper 604, 1940, 65 pp.

54/ Davis, J. D., Coke and By-Product Yields from Various Coals: Iron and Steel Eng., vol. 17, 1940, pp. 47-62.

55/ Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and Byproduct-Making Properties of American Coals and Their Determination: Bureau of Mines Monograph 5, 1934, 164 pp.

Table 1 gives the sources and analyses of the five coals, of the coals blended with them, and of the blends. None contains more than 6.4 percent ash and 1.0 percent sulfur; these amounts are low enough for the manufacture of metallurgical coke. The high-volatile coals yielded coke of moderate size, and the pieces were fractured enough to prevent high strength in the shatter test. The cokes from the medium-volatile coals were dense, blocky, and only slightly fractured; they were unusually strong. The medium-volatile coals and the blends of coal 61 with coals 56 and 57 expanded the retorts, although most high-volatile A bituminous coals do not expand the retorts when blended with Pocahontas No. 3- and No. 4-bed coals in these proportions.

Table 2 gives the yields of products of carbonization from coals 60 to 63, inclusive, from blending coals 28, 56, and 57, and from the blends. High-volatile coals 28, 61, 62, and 63 gave high yields of tar, light oil, and ammonium sulfate and low yields of coke; whereas low-volatile coals 56 and 57 gave low yields of tar, light oil, and ammonium sulfate and high yields of coke. Medium-volatile coal 60, as indicated by its intermediate rank, yielded quantities of coke and byproducts intermediate between those obtained from the high- and low-volatile coals. The yield of tar from coal 61 (10.7 gallons per ton) was lower than the yields from other high-volatile coals and differed only slightly from that obtained from medium-volatile coal 60. The differences in the yields of gas from the high-volatile A and medium-volatile coals were small on the basis of volume but were larger on the basis of the heat in gas per pound of coal carbonized. Blending the high-volatile coals with low-volatile coals 56 and 57 increased the yield of coke and decreased the yields of byproducts; blending medium-volatile coal 60 with high-volatile coal 28 decreased the yield of cokes and increased the yield of byproducts.

Table 3 gives the results of physical tests of the cokes obtained from coals 28, 56, 57, 60, 61, 62, 63, and 64 and from blends of these coals on carbonization at 900°C. in the 18-inch retort. The densest cokes were obtained from low-volatile coals 56 and 57; but, as is shown by the percentage of cells in the other cokes, it cannot be concluded that the density (or porosity) of coke is closely related to the rank of coal. The strongest cokes, as measured by the shatter and tumbler tests, were obtained from medium-volatile coals 60 and 64; the cokes from low-volatile coals 56 and 57 were stronger than those from the high-volatile coals. Coal 61 yielded the strongest coke of the three high-volatile A coals; this coke was but slightly weaker than the cokes from the low-volatile Pocahontas coals. Blending the medium-volatile coals with high-volatile coal 28 decreased the strength of the coke. Blending the high-volatile coals with low-volatile coals 56 and 57 increased the strength of the cokes, and this increase was greater for coals 62 and 63 than for coal 61. The two Pocahontas coals are of approximately equal value in improving the strength of the cokes from high-volatile coals 61, 62, and 63 by blending in amounts of 20 and 30 percent.

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TABLE 1. - Analyses of coals, as carbonized[1]

Coal 60. - Lower Freeport bed, Indiana County, Pa.
Coal 61. - No. 1 bed, Bell No. 1 mine, Crittenden County, Ky.
Coal 62. - Powellton bed, Elk Creek No. 1 mine, Logan County, W. Va.
Coal 63. - Lower Hignite bed, Atlas mine, Bell County, Ky.
Coal 64. - Bakerstown bed, No. 23 mine, Tucker County, W. Va.
Coal 56. - Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Coal 57. - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28. - Pittsburgh bed, Warden mine, Allegheny County, Pa.

| Coal No.[2] | Dry, mineral-matter-free fixed carbon | Moist, mineral-matter-free B.t.u. | Proximate, percent | | | | Ultimate, percent | | | | | Heating value, B.t.u. per lb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Moisture | Volatile matter | Fixed carbon | Ash | Hydrogen | Carbon | Nitrogen | Oxygen | Sulfur | |
| 60 | 73.4 | 15,410 | 2.0 | 24.9 | 66.7 | 6.4 | 5.1 | 81.2 | 1.3 | 5.3 | 0.7 | 14,310 |
| 60A | 65.0 | 15,020 | 1.9 | 32.8 | 59.8 | 5.5 | 5.3 | 79.7 | 1.5 | 7.1 | .9 | 14,100 |
| 60B | 65.3 | 15,110 | 1.6 | 32.2 | 60.6 | 5.6 | 5.3 | 79.9 | 1.5 | 6.8 | .9 | 14,170 |
| 61 | 64.4 | 14,390 | 5.4 | 32.3 | 57.3 | 5.0 | 5.5 | 76.5 | 1.3 | 11.0 | .7 | 13,590 |
| 61A | 68.7 | 14,790 | 3.5 | 29.0 | 62.4 | 5.1 | 5.2 | 79.6 | 1.3 | 8.1 | .7 | 13,950 |
| 61B | 70.1 | 14,780 | 3.4 | 27.7 | 63.6 | 5.3 | 5.1 | 79.5 | 1.3 | 8.2 | .6 | 13,910 |
| 61C | 68.8 | 14,600 | 4.2 | 28.7 | 61.8 | 5.3 | 5.1 | 78.4 | 1.3 | 9.1 | .8 | 13,740 |
| 61D | 70.7 | 14,640 | 4.4 | 26.9 | 63.3 | 5.4 | 5.1 | 78.8 | 1.3 | 8.6 | .8 | 13,760 |
| 62 | 64.7 | 15,080 | 2.5 | 33.7 | 61.1 | 2.7 | 5.4 | 82.5 | 1.5 | 7.3 | .6 | 14,620 |
| 62A | 68.3 | 15,270 | 1.6 | 30.4 | 64.8 | 3.2 | 4.9 | 83.1 | 1.5 | 6.7 | .6 | 14,720 |
| 62B | 70.5 | 15,390 | 1.2 | 28.3 | 66.6 | 3.9 | 5.1 | 83.4 | 1.4 | 5.6 | .6 | 14,720 |
| 62C | 69.3 | 15,300 | 1.4 | 29.5 | 65.6 | 3.5 | 5.2 | 83.1 | 1.4 | 6.1 | .7 | 14,700 |
| 62D | 70.4 | 15,290 | 1.4 | 28.4 | 66.5 | 3.7 | 5.1 | 83.1 | 1.4 | 6.0 | .7 | 14,660 |
| 63 | 60.8 | 14,680 | 2.9 | 36.4 | 55.6 | 5.1 | 5.6 | 77.3 | 1.6 | 9.8 | .6 | 13,850 |
| 63A | 64.5 | 14,920 | 1.8 | 33.3 | 59.5 | 5.4 | 5.3 | 79.2 | 1.6 | 7.8 | .7 | 14,020 |
| 63B | 66.5 | 14,960 | 1.9 | 31.5 | 61.2 | 5.4 | 5.2 | 79.7 | 1.6 | 7.4 | .7 | 14,060 |
| 63C | 64.3 | 14,830 | 2.6 | 33.2 | 58.6 | 5.6 | 5.2 | 78.6 | 1.5 | 8.5 | .6 | 13,910 |
| 63D | 67.8 | 14,930 | 2.3 | 30.1 | 62.0 | 5.6 | 5.1 | 79.3 | 1.5 | 7.8 | .7 | 14,000 |
| 64 | 77.1 | 15,450 | 2.2 | 21.6 | 70.5 | 5.7 | 4.8 | 82.1 | 1.6 | 4.8 | 1.0 | 14,470 |
| 64A | 65.6 | 15,120 | 2.0 | 32.3 | 60.3 | 5.4 | 5.4 | 79.7 | 1.5 | 7.1 | .9 | 14,210 |
| 64B | 66.4 | 15,120 | 2.0 | 31.6 | 61.2 | 5.2 | 5.3 | 80.1 | 1.6 | 6.9 | .9 | 14,240 |
| 56 | 81.7 | 15,520 | 1.6 | 17.4 | 74.5 | 6.5 | 4.4 | 83.7 | 1.2 | 3.6 | .6 | 14,400 |
| 57 | 83.3 | 15,510 | 1.4 | 16.0 | 75.6 | 7.0 | 4.3 | 82.6 | 1.3 | 3.7 | 1.1 | 14,300 |
| 28 | 61.8 | 15,080 | 1.5 | 36.0 | 57.3 | 5.2 | 5.4 | 79.6 | 1.6 | 7.2 | 1.0 | 14,200 |

1/ Analyses by H. M. Cooper, chemist, Bureau of Mines.

2/ Coals 60A and 64A contain 80 percent and coals 60B and 64B 70 percent Pittsburgh coal (No. 28); coals 61A, 62A, and 63A contain 20 percent and coals 61B, 62B, and 63B contain 30 percent Pocahontas No. 3 coal (No. 56); coals 61C, 62C, and 63C contain 20 percent and coals 61D, 62D, and 63D contain 30 percent Pocahontas No. 4 coal (No. 57).

## TABLE 2. - Yields of carbonization products obtained at 900°C. in the 18-inch retort

Coal 60. - Lower Freeport bed, Indiana County, Pa.
Coal 61. - No. 1 bed, Bell No. 1 mine, Crittenden County, Ky.
Coal 62. - Powellton bed, Elk Creek No. 1 mine, Logan County, W. Va.
Coal 63. - Lower Hignite bed, Atlas mine, Bell County, Ky.
Coal 56. - Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Coal 57. - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28. - Pittsburgh bed, Warden mine, Allegheny County, Pa.

| Coal No.[1] | Coke, percent | Yields per ton of coal | | | | | Liquor, percent | B.t.u. in gas per pound of coal |
|---|---|---|---|---|---|---|---|---|
| | | Gas, cubic feet | Tar, gallons | Light oil in gas, gallons | $(NH_4)_2SO_4$, pounds | | | |
| 60 | 76.5 | 10,350 | 10.0 | 2.08 | 15.7 | | 4.1 | 2,980 |
| 60A | 70.9 | 10,500 | 13.3 | 3.29 | 20.0 | | 5.0 | 3,130 |
| 60B | 71.5 | 10,450 | 13.4 | 3.02 | 19.6 | | 4.9 | 3,070 |
| 61 | 68.0 | 10,500 | 10.7 | 3.36 | 22.5 | | 8.7 | 3,050 |
| 61A | 71.7 | 10,100 | 9.4 | 2.69 | 22.5 | | 8.1 | 2,940 |
| 61B | 73.0 | 9,950 | 9.5 | 2.49 | 19.0 | | 7.4 | 2,890 |
| 61C | 71.7 | 10,000 | 9.4 | 2.66 | 23.1 | | 8.6 | 2,920 |
| 61D | 72.8 | 9,850 | 8.6 | 2.48 | 20.5 | | 7.5 | 2,830 |
| 62 | 69.6 | 10,800 | 13.8 | 3.16 | 19.9 | | 6.2 | 3,270 |
| 62A | 72.8 | 10,450 | 12.3 | 2.79 | 20.9 | | 5.8 | 3,090 |
| 62B | 74.1 | 10,500 | 11.0 | 2.60 | 20.5 | | 5.5 | 3,000 |
| 62C | 72.7 | 10,400 | 12.0 | 2.72 | 21.9 | | 5.7 | 3,050 |
| 62D | 74.5 | 10,550 | 10.8 | 2.79 | 20.3 | | 5.3 | 2,990 |
| 63 | 66.2 | 10,900 | 13.5 | 3.58 | 27.9 | | 7.9 | 3,310 |
| 63A | 70.5 | 10,650 | 11.1 | 3.11 | 26.2 | | 7.0 | 3,140 |
| 63B | 72.2 | 10,700 | 9.9 | 2.64 | 24.7 | | 6.7 | 3,050 |
| 63C | 70.6 | 10,600 | 10.9 | 2.97 | 27.0 | | 7.0 | 3,110 |
| 63D | 72.4 | 10,700 | 9.4 | 2.71 | 26.8 | | 6.6 | 3,080 |
| 56 | 84.0 | 10,450 | 4.1 | 1.36 | 13.4 | | 2.7 | 2,610 |
| 57 | 84.3 | 10,250 | 3.2 | 1.29 | 14.5 | | 2.4 | 2,590 |
| 28 | 68.8 | 10,650 | 14.9 | 2.79 | 19.0 | | 6.4 | 3,230 |

[1] Coal 60A contains 80 percent and coal 60B contains 70 percent Pittsburgh coal (No. 28); coals 61A, 62A, and 63A contain 20 percent and coals 61B, 62B, and 63B contain 30 percent Pocahontas No. 3 coal (No. 56); coals 61C, 62C, and 63C contain 20 percent and coals 61D, 62D, and 63D contain 30 percent Pocahontas No. 4 coal (No. 57).

TABLE 3. - Physical properties of cokes carbonized at 900°C. in the 18-inch retorts

Coal 60. - Lower Freeport bed, Indiana County, Pa.
Coal 61. - No. 1 bed, Bell No. 1 mine, Crittenden County, Ky.
Coal 62. - Powellton bed, Elk Creek No. 1 mine, Logan County, W. Va.
Coal 63. - Lower Hignite bed, Atlas mine, Bell County, Ky.
Coal 64. - Bakerstown bed, No. 23 mine, Tucker County, W. Va.
Coal 56. - Pocahontas No. 3 bed, Buckeye, No. 3 mine, Wyoming County, W. Va.
Coal 57. - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28. - Pittsburgh bed, Warden mine, Allegheny County, Pa.

| Coal No.[1] | True specific gravity | Apparent specific gravity | Cells, percent | Shatter test, cumulative percent upon - | | | | Tumbler test, cumulative percent upon - | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen |
| 60 | 1.85 | 0.80 | 56.8 | 66.4 | 88.9 | 96.1 | 98.7 | 20.3 | 54.0 | 69.8 | 75.6 |
| 60A | 1.86 | .83 | 55.4 | 50.7 | 82.4 | 94.2 | 98.2 | 3.6 | 31.5 | 61.7 | 71.2 |
| 60B | 1.86 | .84 | 54.8 | 46.2 | 83.2 | 94.8 | 98.3 | 3.7 | 32.7 | 62.5 | 71.7 |
| 61 | 1.84 | .80 | 56.5 | 57.1 | 81.7 | 92.7 | 98.1 | 5.0 | 26.0 | 51.0 | 66.3 |
| 61A | 1.86 | .84 | 54.8 | 62.9 | 83.5 | 94.1 | 98.3 | 7.4 | 31.3 | 56.6 | 70.9 |
| 61B | 1.85 | .84 | 54.6 | 58.5 | 82.0 | 93.9 | 98.4 | 6.4 | 28.8 | 55.1 | 71.1 |
| 61C | 1.86 | .83 | 55.4 | 63.6 | 84.7 | 94.3 | 98.4 | 9.6 | 34.9 | 57.1 | 70.9 |
| 61D | 1.87 | .83 | 55.5 | 62.0 | 84.2 | 94.9 | 98.3 | 7.3 | 32.8 | 57.7 | 71.8 |
| 62 | 1.83 | .83 | 54.6 | 35.5 | 72.0 | 92.7 | 98.6 | 1.2 | 20.4 | 58.7 | 73.4 |
| 62A | 1.82 | .83 | 54.4 | 52.8 | 82.0 | 94.9 | 98.4 | 2.5 | 28.9 | 59.5 | 73.6 |
| 62B | 1.84 | .85 | 53.8 | 43.0 | 79.0 | 94.9 | 98.4 | 5.7 | 28.5 | 60.7 | 74.7 |
| 62C | 1.84 | .84 | 54.3 | 41.9 | 75.7 | 94.3 | 98.6 | 3.0 | 27.1 | 63.7 | 75.7 |
| 62D | 1.83 | .86 | 53.0 | 39.8 | 79.9 | 94.5 | 98.5 | 4.0 | 28.8 | 63.2 | 75.5 |

[1] Coals 60A and 64A contain 80 percent and coals 60B and 64B contain 70 percent Pittsburgh coal (No. 28); Coals 61A, 62A, and 63A contain 20 percent and coals 61B, 62B, and 63B contain 30 percent Pocahontas No. 3 coal (No. 56); coals 61C, 62C, and 63C contain 20 percent and coals 61D, 62D, and 63D contain 30 percent Pocahontas No. 4 coal (No. 57).

**TABLE 3.** - Physical properties of cokes carbonized at 900°C. in the 18-inch retorts (Cont'd)

Coal 60. - Lower Freeport bed, Indiana County, Pa.
Coal 61. - No. 1 bed, Bell No. 1 mine, Crittenden County, Ky.
Coal 62. - Powellton bed, Elk Creek No. 1 mine, Logan County, W. Va.
Coal 63. - Lower Hignite bed, Atlas mine, Bell County, Ky.
Coal 64. - Bakerstown bed, No. 23 mine, Tucker County, W. Va.
Coal 56. - Pocahontas No. 3 bed, Buckeye, No. 3 mine, Wyoming County, W. Va.
Coal 57. - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28. - Pittsburgh bed, Warden mine, Allegheny County, Pa.

| Coal No.[1] | True specific gravity | Apparent specific gravity | Cells, percent | Shatter test, cumulative percent upon - |  |  |  | Tumbler test, cumulative percent upon - |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen |
| 63 | 1.86 | 0.81 | 56.5 | 28.6 | 59.9 | 81.0 | 97.6 | .0 | 1.3 | 23.7 | 72.0 |
| 63A | 1.87 | .83 | 55.6 | 52.1 | 78.8 | 91.0 | 98.0 | 2.2 | 20.0 | 48.7 | 70.5 |
| 63B | 1.87 | .84 | 55.1 | 47.2 | 78.2 | 92.7 | 98.1 | 3.8 | 22.9 | 53.0 | 71.2 |
| 63C | 1.88 | .83 | 55.9 | 45.5 | 75.8 | 90.6 | 98.0 | 1.1 | 17.6 | 48.0 | 70.6 |
| 63D | 1.89 | .83 | 56.1 | 52.9 | 80.9 | 92.8 | 98.2 | 4.4 | 25.5 | 53.1 | 71.3 |
| 64 | 1.86 | .87 | 53.2 | 60.3 | 88.0 | 97.1 | 99.0 | 11.4 | 49.6 | 72.3 | 76.9 |
| 64A | 1.85 | .84 | 54.6 | 42.6 | 82.9 | 95.4 | 98.4 | 6.8 | 31.0 | 65.1 | 74.2 |
| 64B | 1.86 | .84 | 54.8 | 44.7 | 81.8 | 95.8 | 98.6 | 2.9 | 34.6 | 66.9 | 75.4 |
| 56 | 1.86 | .90 | 51.6 | 59.9 | 83.3 | 94.6 | 98.5 | 5.2 | 32.5 | 59.3 | 71.5 |
| 57 | 1.88 | .91 | 51.6 | 62.2 | 87.3 | 95.2 | 98.3 | 9.0 | 34.4 | 60.7 | 70.6 |
| 28 | 1.85 | .88 | 52.5 | 33.1 | 68.0 | 93.2 | 98.6 | 1.8 | 20.4 | 55.2 | 71.5 |

[1] Coals 60A and 64A contain 80 percent and coals 60B and 64B contain 70 percent of Pittsburgh coal (No. 28); coals 61A, 62A, and 63A contain 20 percent and coals 61B, 62B, and 63B contain 30 percent Pocahontas No. 3 coal (No. 56); coals 61C, 62C, and 63C contain 20 percent and coals 61D, 62D, and 63D contain 30 percent Pocahontas No. 4 coal (No. 57).

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Coals 60 and 64 formed relatively large amounts of sponge coke at the middle of the charge when carbonized at medium and low temperatures. This spongy structure was so pronounced at 500° and 600°C. that voids were formed. These voids, which were 3 to 6 inches in diameter and 12 to 16 inches in length, are illustrated in figure 5. These principal observations relating to the formation of sponge coke or voids have been made: (1) The size of the voids, considering a single coal, are in approximate proportion to the pressure of gas formed in the interior of the charge; (2) voids have been formed only in charges of coals having unusually wide ranges of plasticity; these ranges for three coals forming voids at 500° and 600°C. are: No. 59,[56] 106°; No. 60, 105°; No. 64, 100°C.

The fusion temperatures of the ash from 46 coals and the cokes made from them at 500°, 600°, 700°, 800°, 900°, 1,000°, and 1,100°C. were compared in a study of the relationship of the fusion temperatures of the ash from coal and coke.[57] A trend toward lower fusion temperatures for the ash from coke was noted, and the difference increased with rise in carbonizing temperature to the maximum of 37°F. for the 1,100°C. cokes. As the difference is within the limits of error of the determination of fusion temperatures of ash cokes are known to be contaminated by iron during crushing, and this extraneous iron might decrease the fusion temperature of the ash; high-temperature cokes are harder and are liable to be contaminated more than cokes made at low or medium temperatures, therefore the study does not indicate that the fusion temperature of ash is affected by the process of coking.

Plasticity. - The plastic properties of all coals and blends studied in the Survey of the Carbonizing Properties of American Coals during the year (table 1) were determined by the Agde-Damm dilatometer and by the Davis and Gieseler plastometer test methods.[58] Many tests were made by these methods on oxidized coals[59] and petrographic components of coals.[60]

The plastic properties of the high-volatile A coals 61, 62, and 63 are characteristic of this rank of coal. Coal 63 (Lower Hignite) is of lower rank than the others; and its plastic properties, as expected, differed from those of coals 61 and 62, which are closer to the average for high-volatile A coals.

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[56] Coal 59 was high-volatile A bituminous from the Upper Freeport bed in Monongalia County, W. Va.

[57] Reynolds, D. A., Relationship of Ash-fusion Temperatures of Coal and Coke: Bureau of Mines Rept. of Investigations 3505, 1940, 6 pp.

[58] Brewer, R. E., and Atkinson, R. G., Plasticity of Coals - Its Measurement and Relation to Quality of Coke Produced: Ind. Eng. Chem., anal. ed., vol. 8, 1936, pp. 443-449.

Brewer, R. E., and Triff, J. E., Measurement of Plastic Properties of Bituminous Coals. Comparison of Gieseler and Davis Plastometer and Agde-Damm Dilatometer Methods: Ind. Eng. Chem., anal. ed., vol. 11, 1939, pp. 242-247.

[59] Brewer, R. E., Holmes, C. R., and Davis, J. D., Effect of Oxidation on Plastic Properties of Bituminous Coking Coals: (In press).

[60] Brewer, R. E., Holmes, C. R., and Davis, J. D., Plastic Properties of Bituminous Coking Coals - Effect of Petrographic Composition: Ind. Eng. Chem., vol. 32, 1940, pp. 792-797.

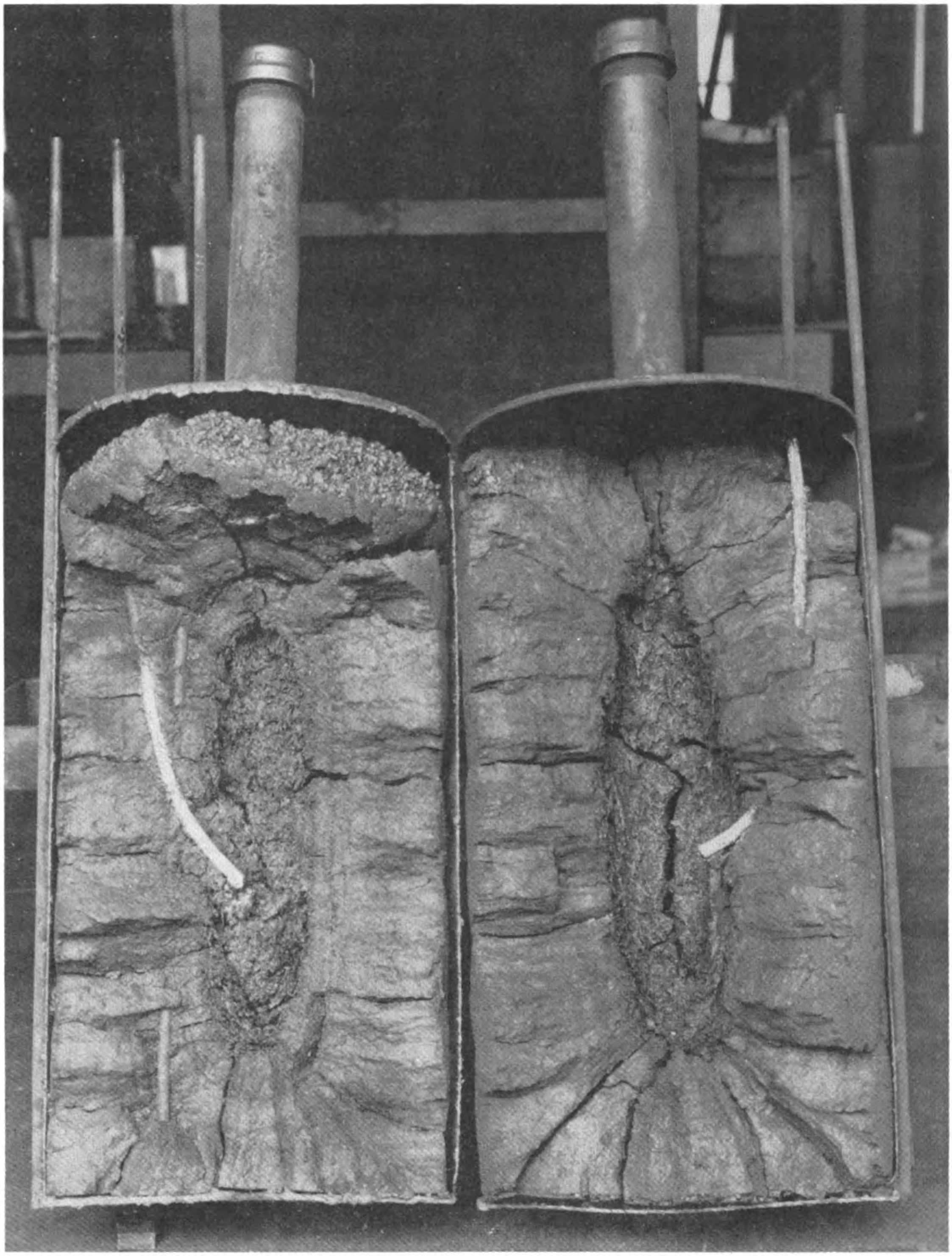

Figure 5.- Voids at center of charge in 600° C. cokes from Lower Freeport and Bakerstown coals.

Medium-volatile coals 60 and 64 had higher characteristic temperatures and were less fluid in comparison with the high-volatile A coals. The plastic ranges of coals 60 and 64, as measured by the Davis plastometer, were 106° and 100°C., respectively. Plastic ranges thus measured seldom are this great; when they are, they may be a factor in the formation of spongy coke, which was pronounced with these coals. That wide ranges of plasticity are not characteristic of medium-volatile coals is indicated by the fact that two representative medium-volatile coals from the Sewell bed, Nos. 27 and 55, have plastic ranges of 50° and 61°C., respectively.

The blending of high-volatile coals 61, 62, and 63 with low-volatile Pocahontas No. 3 and No. 4 coals increased the characteristic temperatures, reduced the fluidity, and increased the maximum resistance (Davis plastometer) observed by the three test methods. These effects were greater when larger proportions of the low-volatile coals were used. Pocahontas No. 4 coal produced greater changes than Pocahontas No. 3 coal in equal proportions with these coals; as the Pocahontas No. 4 coal is of slightly higher rank than the Pocahontas No. 3 this difference was expected.

Effect of Weathering on Coking Properties. - Representative samples from two beds of coal were subjected to accelerated weathering in air at 99.3°C.[61] A sample of Upper Freeport coal[62] consumed 2.60 percent oxygen in 18.4 days, and Lower Freeport coal, No. 60, consumed 2.43 percent in 18.6 days; the oxidation ratios of these coals, therefore, do not differ significantly. Degradation of the coke-making property by oxidation, as evinced by physical tests of the cokes, was more rapid for the Upper Freeport coal, although neither was unusually sensitive in this respect.

The results of the study of the effect of oxidation on the carbonizing properties of representative coking coals were summarized.[63] In general, progressive oxidation results first in decreased size of pores in coke, followed by poor fusion, and finally complete loss of coking power. The apparent specific gravity of coke increases with oxidation of the coal, and this change is accompanied by decreases both in strength of coke and in yields of byproducts (except ammonia). The yield of tar, physical properties of coke, and agglutinating value are sensitive measures of the extent of oxidation. The majority of coals tested show serious impairment of coking power before they are oxidized enough to decrease the heating value by 1 percent and before their ultimate and proximate analyses show changes definitely greater than the experimental error of the analysis. The relationship between

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[61] Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures - Rates of the Oxidation Reaction for Representative Coking Coals: Ind. Eng. Chem., vol. 32, 1940, pp. 249-256.

[62] Upper Freeport bed, Morgantown district, Monongalia County, W. Va., coal 59.

[63] Schmidt, L. D., Elder, J. L., and Davis, J. D., Atmospheric Oxidation of Coal at Moderate Temperatures - Effect of Oxidation on the Carbonizing Properties of Representative Coking Coals: Ind. and Eng. Chem., vol. 32, 1940, pp. 548-555.

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volatile matter and the sum of original oxygen content plus the amount of oxygen required to cause a 20 percent reduction in the hardness of coke is shown in figure 6. The amount of oxygen required to cause a decrease of 20 percent in hardness of coke shows a threefold range between the most sensitive and the least sensitive coals. This oxygen requirement increases with the volatile matter and decreases with the oxygen content of fresh coals.

Determination of Swelling Properties of Coals During Coking Process. - No empirical test such as those used by the Bureau of Mines to determine expanding properties will give results directly applicable to all industrial coking processes because carbonizing conditions vary for different processes. One of the fundamental factors in coal expansion is shrinkage of the coke after it is formed in the oven. A particular investigation of this variable was made; results obtained in a group of tests where heating was continued after all the coal was coked are given in table 4. The linear shrinkage was measured in the direction of flow of heat. The shrinkage for the same range of temperature calculated from the mean of the volume-shrinkage tests on granular cokes is given for comparison. The results of another group of coke-shrinkage tests where the shrinkage, perpendicular to the flow of heat was measured are illustrated in figure 7, which shows the entire sole-heated oven charges from three coals. The area of the coke at temperature of formation, regardless of what the temperature of formation might be, is the area of the oven, for coke is formed from plastic coal in which a crack cannot exist. The outline shows the dimensions of the oven; the shrinkage after formation, therefore, is the sum of the areas of the remaining cracks and the blank space enclosed by the lines. The final temperature in each of these tests was approximately the same; and the shrinkage is also the same, even though the coals differ widely in rank and expansion behavior. The investigation has shown that, within limits of practical application, all cokes shrink to the same extent between formation and pushing temperatures.

In figure 8 the results of two tests of coal 59 are given. One test was made at constant volume and one under constant pressure conditions. The pressure developed by the charge in the constant-volume test is between 1.0 and 1.4 pounds per square inch during most of the carbonizing period. Certain other coals have given this type of pressure curve, but some coals continually build up pressure as long as any uncoked coal remains in the oven. Figure 9 gives the results of two tests of Sewell-bed coal; one charge was heated from one side, the other from two sides. The pressure peak at 9 hours apparently occurs when the two plastic layers meet in the center of the charge. Up to the present, only a few tests have been made in which the charge has been heated from both sides; therefore, the relative merits of one- or two-sided heating will not be discussed.

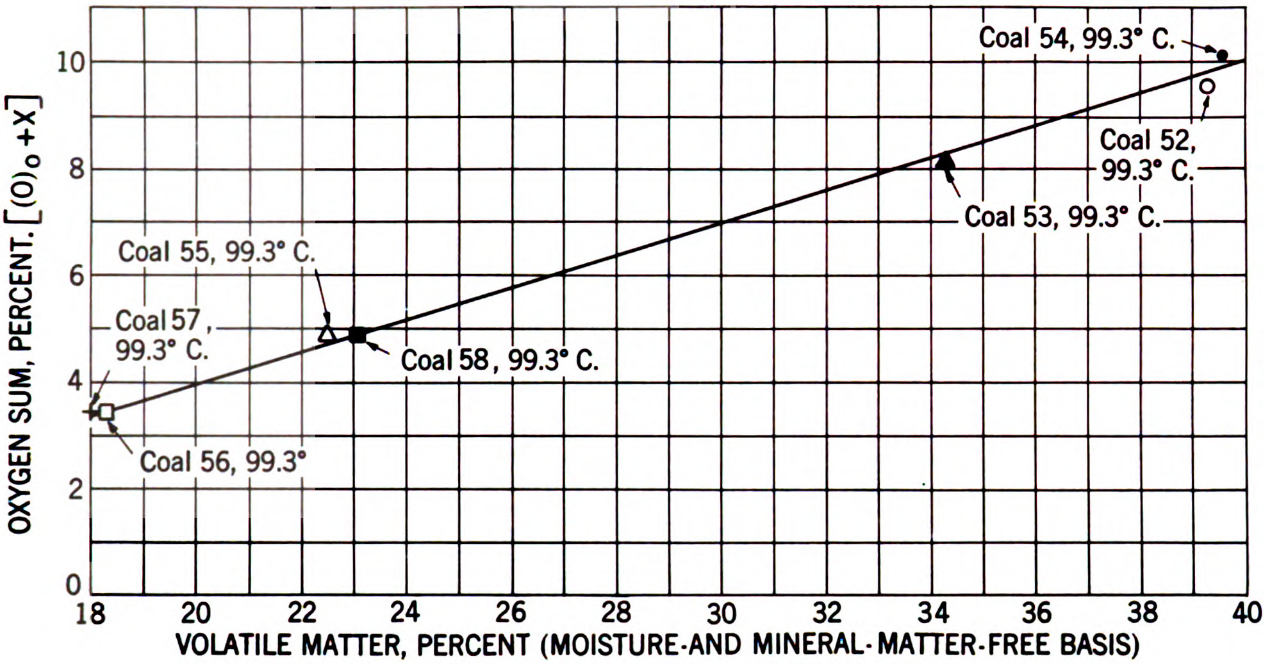

Figure 6.- Relationship between volatile matter and the sum of original oxygen plus the additional oxygen required to cause a 20-percent reduction in hardness of coke.

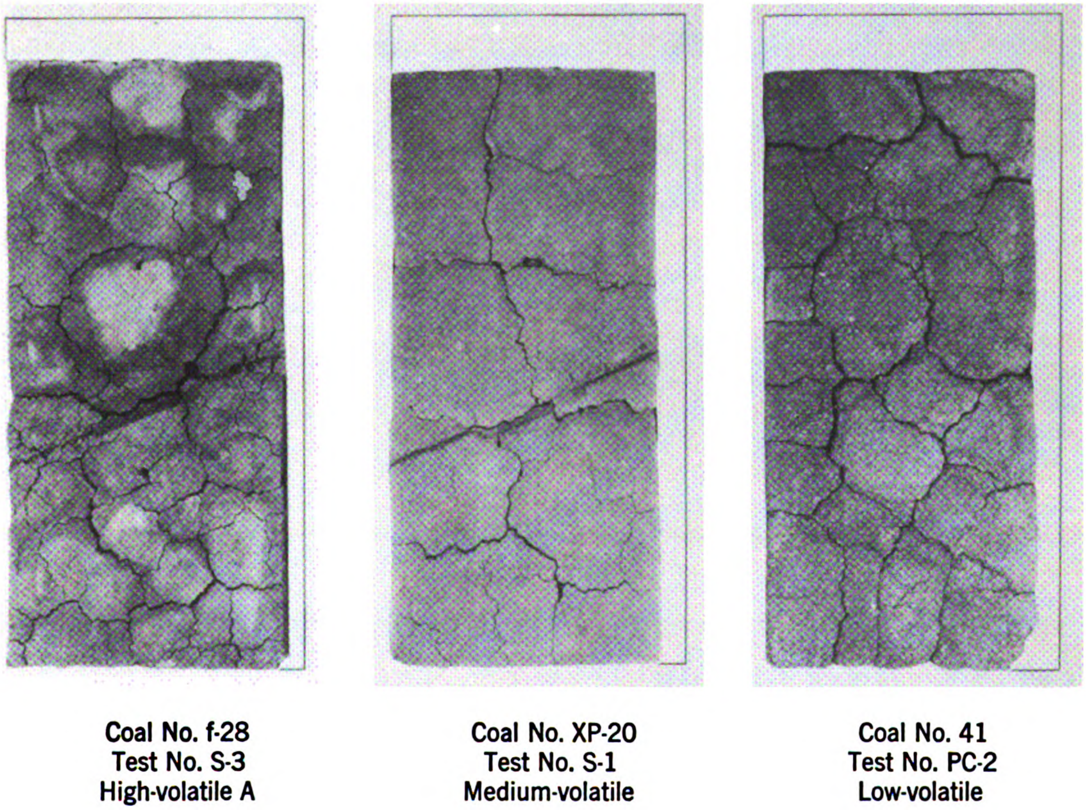

Figure 7.- Shrinkage of high-temperature cokes.

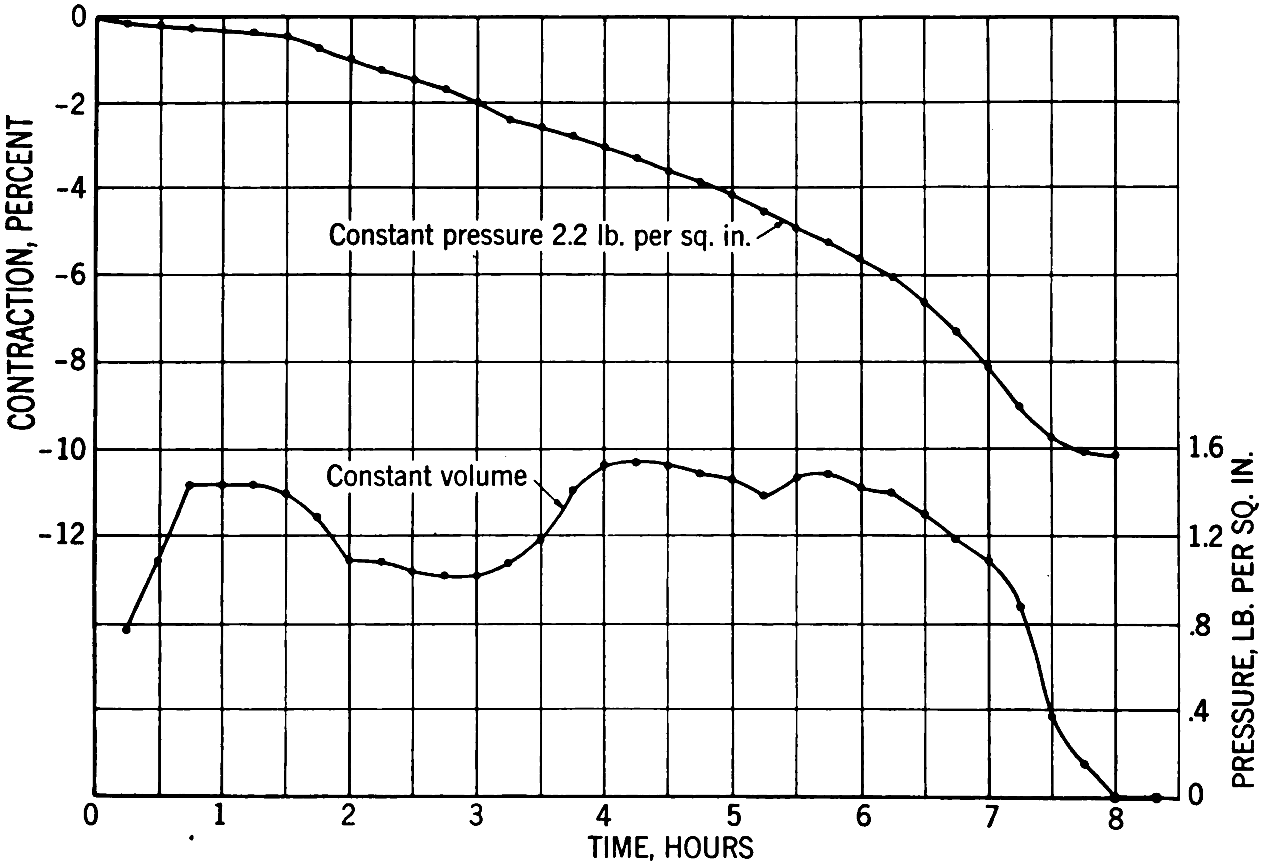

**Figure 8.- Comparison of constant-volume and constant-pressure tests, other conditions identical (coal 59).**

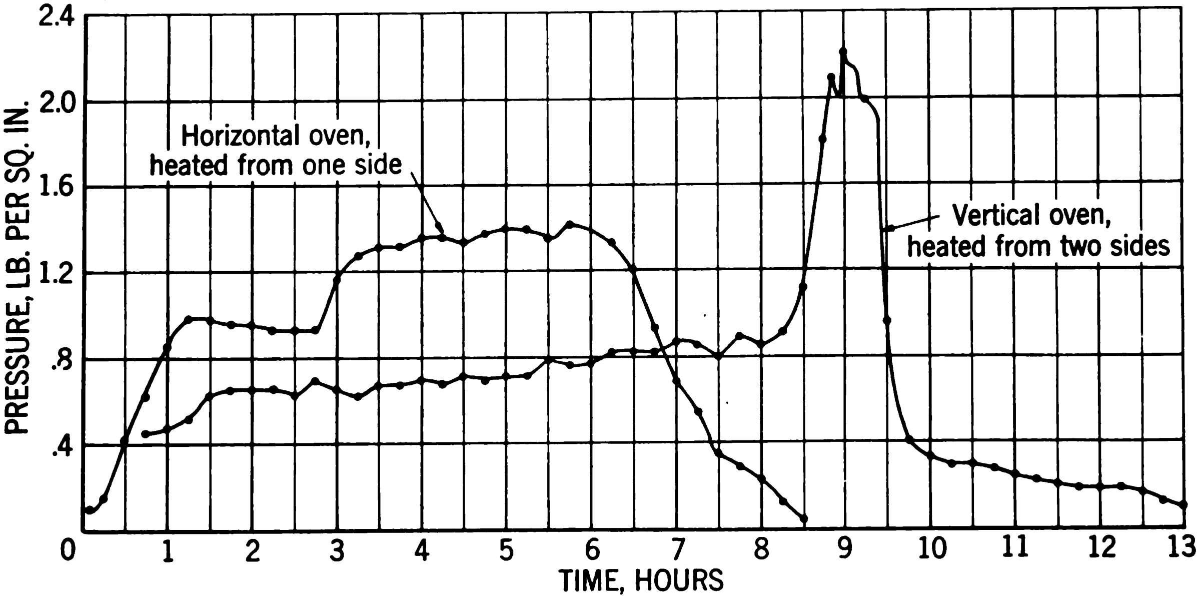

**Figure 9.- Comparison of pressures developed with one- and two-sided heating (coal XPmb 18, constant-volume tests).**

TABLE 4. - Linear shrinkage of coke. Comparison of directly-measured shrinkage of coke pieces with that calculated from volume shrinkage of granular coke[1]

| Coal No. | Rank of coal (volatile) | Temperature of coke, °C. | | | | | Linear shrinkage, percent | | Deviation, measured from calculated |
|---|---|---|---|---|---|---|---|---|---|
| | | At start of test | | At end of test | | Increase in average temperature | Coke pieces (measured) | Granular coke (calculated) | |
| | | Range | Average | Range | Average | | | | |
| **XP-20** | Medium | 485-770[2] | 652 | 780-975 | 881 | 229 | 4.80 | 4.59 | +0.21 |
| **XP-20** | do | 645-775 | 718 | 950-1050 | 997 | 279 | 4.15 | 4.07 | +0.08 |
| 64 | do | 545-705 | 631 | 890-1030 | 967 | 336 | 6.01 | 6.12 | -0.11 |
| 58[3] | do | 540-725 | 639 | 900-1030 | 962 | 323 | 5.13 | 5.82 | - .69 |
| 60 | do | 510-680 | 597 | 890-1035 | 971 | 374 | 7.16 | 7.20 | - .04 |
| 61 | High | 530-800[2] | 705 | 800-960 | 885 | 180 | 2.87 | 3.22 | - .35 |
| 62 | do | 510-690 | 610 | 915-1050 | 986 | 376 | 7.96 | 6.88 | +1.08 |
| f28 | do | 520-640 | 578 | 910-1020 | 973 | 395 | 8.88 | 7.81 | +1.07 |
| 63 | do | 530-705 | 625 | 900-1040 | 983 | 358 | 6.88 | 6.43 | + .45 |
| 63 | do | 545-660 | 608 | 930-1055 | 1001 | 393 | 7.88 | 7.11 | + .77 |

Average algebraic deviation of high-volatile coals = +0.60.
Average algebraic deviation of low- and medium-volatile coals = -0.11.
Average arithmetic deviation of all coals = 0.49.

[1] Linear shrinkage of granular coke over the same range of temperature as that obtained in a test on coke pieces is calculated from a mean curve of shrinkage versus temperature plotted from data collected in tests on granular coke.

[2] Temperatures in these tests are not as reliable as in the others.

[3] Lower Banner bed, Keen Mountain mine, Buchanan County, Va.

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## Correlation of Small-scale Laboratory Tests with Microscopical Composition of Coal

Low-temperature carbonization tests have been useful in correlating the microscopical composition of coals with their coke- and byproduct-making properties. Nearly all the coals studied in the BM-AGA carbonization tests have been classified microscopically by means of a series of thin sections prepared from top to bottom of the coal bed. As most coals are mixtures of different types, it has been the procedure to separate these microscopically classified layers from column samples and determine their coke- and byproduct-making properties by the Fischer low-temperature assay. Other properties of the layers are determined by chemical analysis and agglutinating tests.

Data obtained on the petrographic layers of the coals in the BM-AGA series are summarized in a technical paper on splint coals.[64] This report discusses the origin, petrography, geographical distribution, geological occurrence, hydrogenation properties, chemical analysis, agglutinating values and low-temperature assay yields of typical Appalachian splint coals and compares these chemical and physical properties with the associated bright coals.

The types of coal in 55 columns selected from representative coals in the Appalachian region are listed in table 5. When these coals are arranged according to age the importance of splint coal in beds of the Upper Pottsville (Kanawha formation) is shown; beds above and below the Upper Pottsville consist principally of bright coal.

The ultimate and proximate analyses of splint coal show interesting relationships when compared with the associated bright coal. When compared on the dry, mineral-matter-free basis, the splint layers have a higher content of carbon than the bright layers of the same bed. Generally they have a higher content of ash and a higher ash-fusion temperature. The bright coals generally have higher moisture, hydrogen, nitrogen, and oxygen contents and lower calorific values. The volatile matter may vary in either direction, depending on the petrographic composition of the bright or splint coal. Components such as spores and resins give unusually high volatile matter.

The low-temperature carbonization assay yields of the splint and bright coals, when compared on the basis of the coal free of moisture and mineral matter, indicate that the volume of gas obtained from splint coal is nearly always less than that obtained from the associated bright coal. The yields of coke and of tar and oil have been found to be closely related to the chemical analyses of the splint and bright coals, and from the analyses the yields of these products can be predicted accurately.

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[64] Sprunk, G. C., Ode, W. H., Selvig, W. A., and O'Donnell, H. J., Splint Coals of the Appalachian Region: Their Occurrence, Petrography, and Comparison of Chemical and Physical Properties with Associated Bright Coals: Bureau of Mines Tech. Paper 615, 1940, 59 pp.

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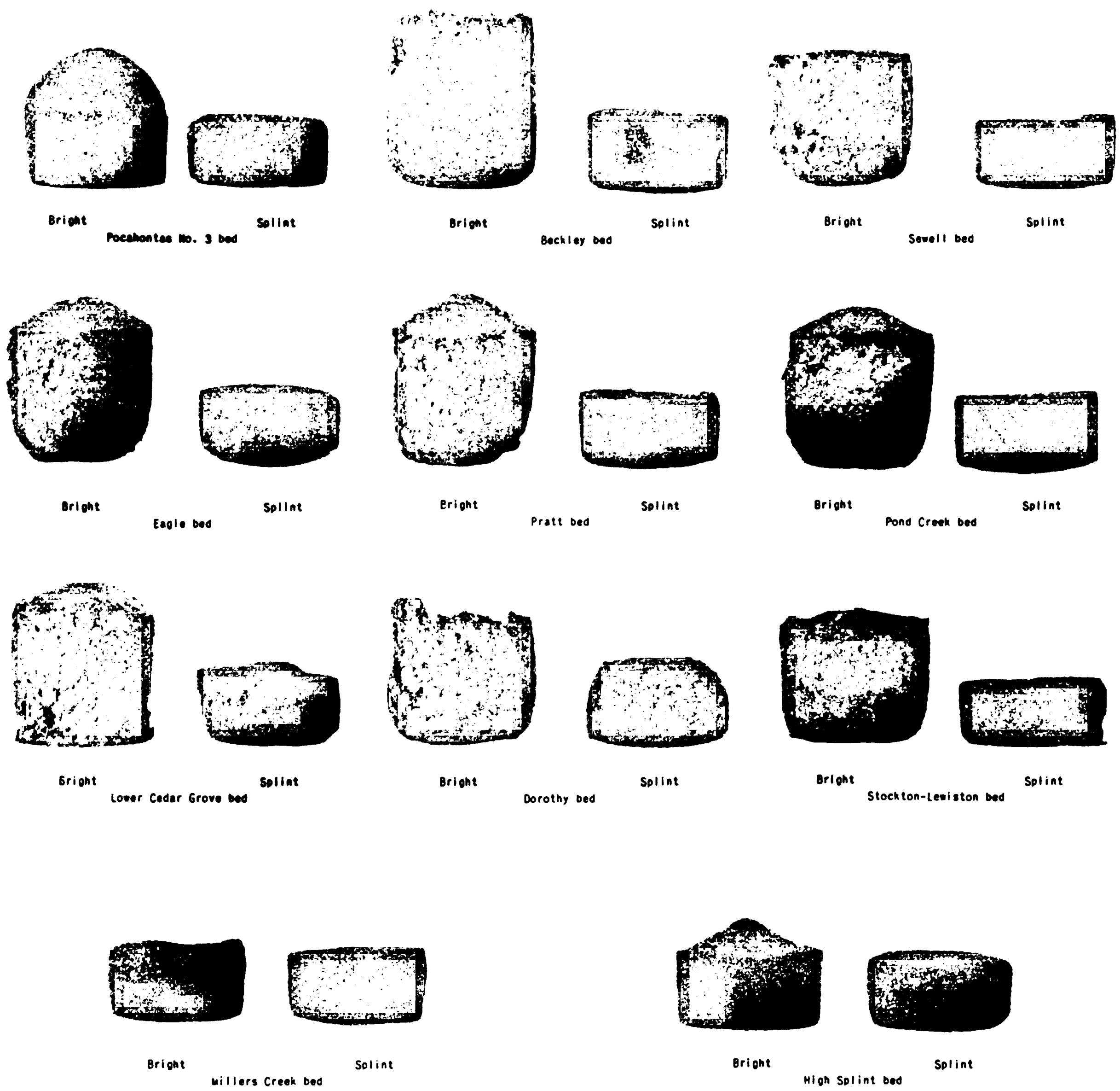

Figure 10.- Coke residues from Fischer low-temperature assay.

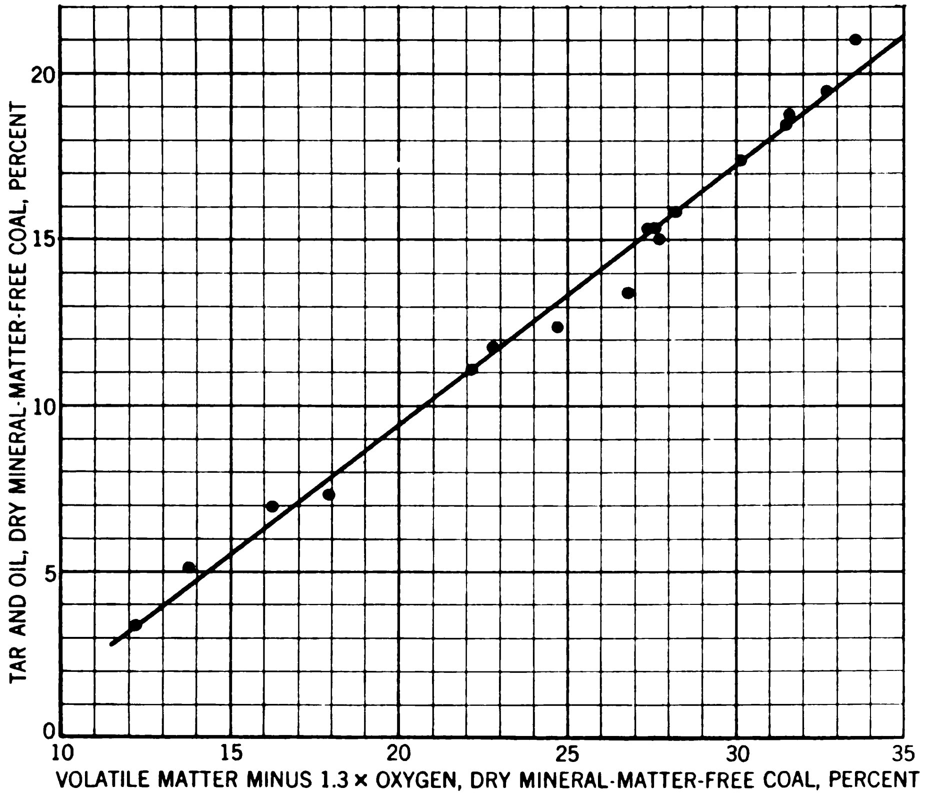

**Figure 13.**- Relation of yield of low-temperature tar and oil to volatile matter minus 1.3x oxygen content of splint coals, dry mineral-matter-free basis.

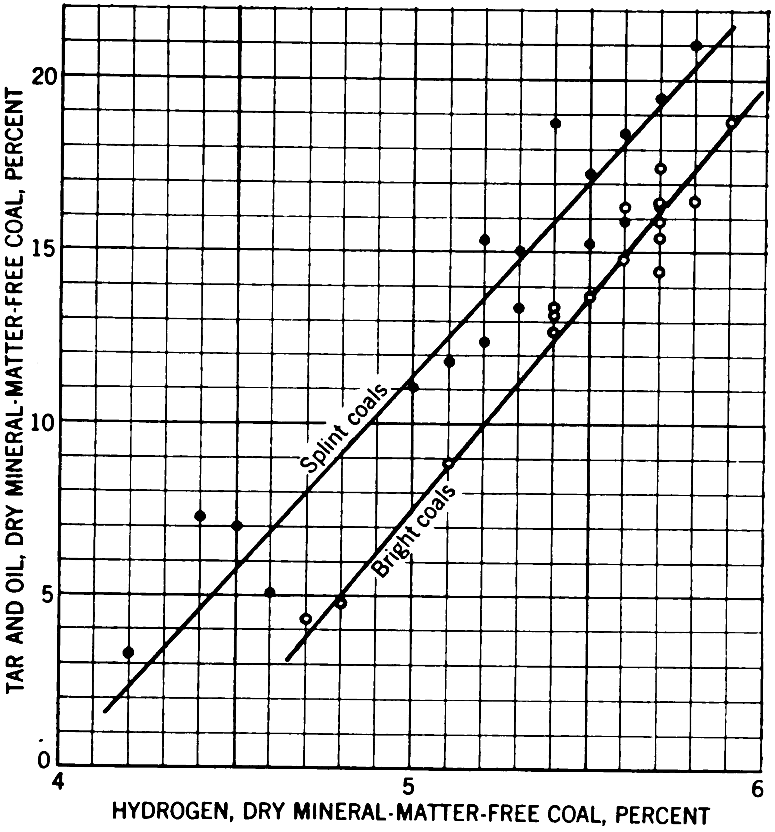

**Figure 14.**- Relation of yield of low-temperature tar and oil to hydrogen content of bright and splint coals, dry mineral-matter-free basis.

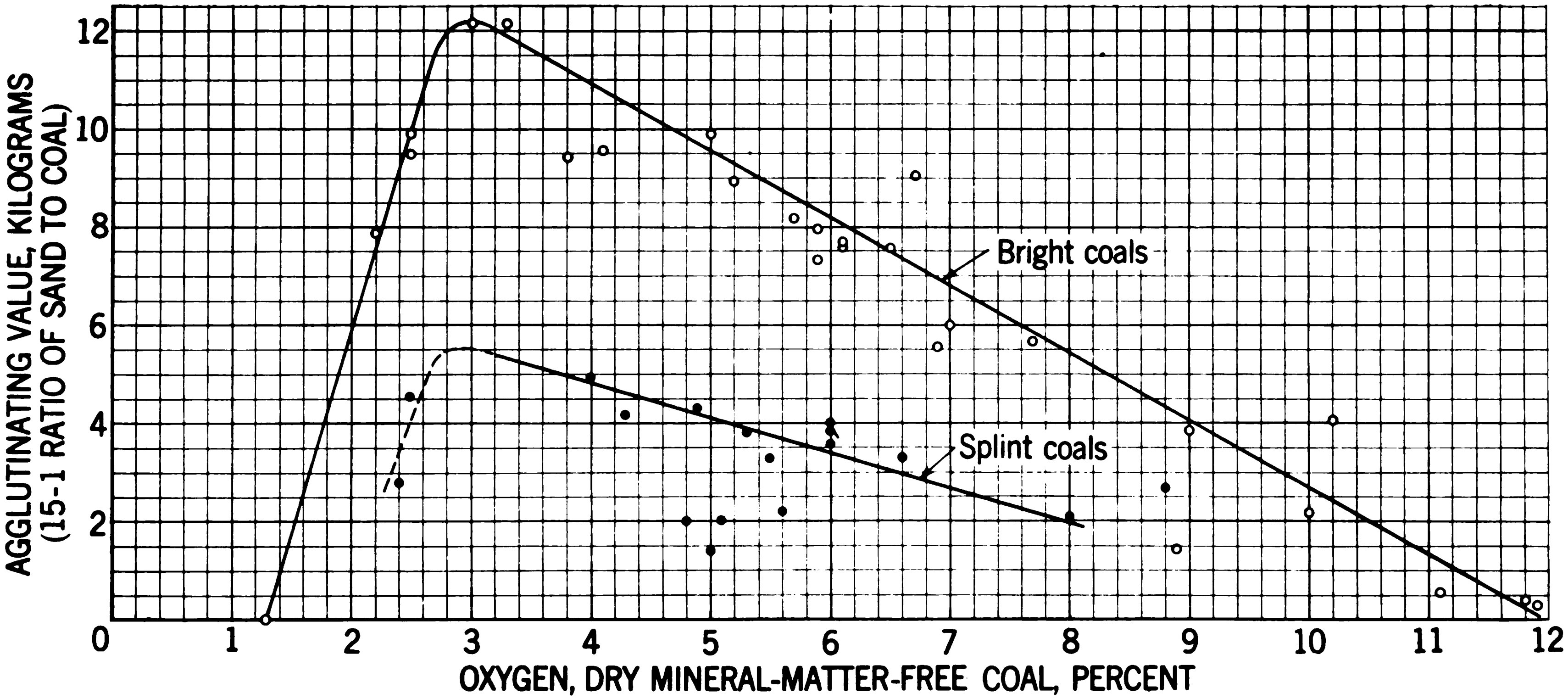

Figure 15.- Relation of agglutinating value to oxygen content of bright and splint coals.

TABLE 5.- Types of coals in beds of Appalachian region arranged according to age, youngest coals at top.

| Bed | State | County | Mine | Age | Type, percent of bed | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Splint | Semi-splint | Bright | Cannel |
| Pittsburgh | Pa. | Fayette | Edenborn | Monongahela | 0 | 8 | 92 | 0 |
| Do. | do. | Allegheny | U. S. Experimental | do. | 3 | 13 | 84 | 0 |
| Do. | do. | Washington | Pittsburgh Terminal No. 9 | do. | 4 | 2 | 94 | 0 |
| Do. | W. Va. | Marion | Consolidation No. 63 | do | 0 | 13 | 87 | 0 |
| Do. | Ohio | Harrison | Apex | do. | 1 | 2 | 97 | 0 |
| Upper Freeport (thick) | Pa. | Allegheny | Wildwood | Allegheny | 0 | 0 | 100 | 0 |
| Upper Freeport | W. Va. | Monongalia | Industrial Collieries No. 21 | do. | 0 | 14 | 86 | 0 |
| Lower Freeport | Pa. | Indiana | Industrial Collieries No. 9 | do. | 2 | 5 | 93 | 0 |
| Upper Kittanning | do. | Cambria | Bethlehem Steel Co. No. 73 | do. | 0 | 0 | 100 | 0 |
| Middle Kittanning | do. | Jefferson | McCrary No. 1 | do. | 0 | 0 | 100 | 0 |
| Lower Kittanning | do. | Cambria | Bethlehem Steel Co. No. 72 | do. | 0 | 0 | 100 | 0 |
| Do. | do. | Jefferson | Hanley Clay No. 3 | do. | 6 | 2 | 92 | 0 |
| Do. | do. | do. | Cowan | do. | 5 | 19 | 76 | 0 |
| Do. | do. | do. | McCrary No. 2 | do. | 9 | 14 | 77 | 0 |
| Do. | do. | Clarion | Jones coal bank | do. | 7 | 0 | 93 | 0 |
| Do. | do. | Armstrong | Cadogan | do. | 7 | 15 | 78 | 0 |
| Do. | do. | Fayette | Indian Creek No. 1 | do. | 0 | 12 | 88 | 0 |
| Clarion | do. | Jefferson | Hanley Clay No. 2 | do. | 0 | 30 | 70 | 0 |
| Do. | do. | Clarion | Sutton No. 9 shaft | do. | 0 | 29 | 71 | 0 |
| Brookville | do. | Jefferson | Conifer No. 1 | do. | 7 | 88 | 5 | 0 |
| Do. | do. | do. | Country bank on Welsh Run | do. | 11 | 74 | 15 | 0 |
| Do. | do. | do. | Minewesser bank | do. | 17 | 81 | 2 | 0 |
| Do. | do. | do. | Baughman bank | do. | 25 | 65 | 10 | 0 |
| Do. | do. | do. | McClellan bank | do. | 23 | 70 | 7 | 0 |
| Do. | do. | Clarion | Sutton No. 9 | do. | 18 | 68 | 14 | 0 |
| Stockton (Lewiston) | W. Va. | Kanawha | Sharon | Pottsville | 22 | 53 | 25 | 0 |
| Coalburg | do. | Boone | Silush | do. | 68 | 32 | 0 | 0 |
| Winifrede (Dorothy) | do. | Kanawha | Carbon Fuel Co. No. 10 | do. | 63 | 20 | 17 | 0 |
| Quakertown (Winifrede[1]) | Ohio | Jackson | Wellston No. 2 strip | do. | 0 | 5 | 95 | 0 |
| Chilton | W. Va. | Logan | Boone No. 2 | do. | 17 | 27 | 56 | 0 |
| Cedar Grove (Upper Thacker) | do. | Mingo | Redjacket Cons. Coal & Coke, Junior | do. | 32 | 39 | 29 | 0 |
| Lower Cedar Grove (Lower Thacker) | do. | do. | do. | do. | 30 | 7 | 63 | 0 |
| Alma | do. | Boone | Spruce River No. 4 | do. | 16 | 0 | 84 | 0 |
| Do. | do. | Mingo | Red Jacket No. 6 | do. | 25 | 14 | 61 | 0 |
| Elkhorn No. 3 (Alma[2], Taggart[3]) | Ky. | Letcher | Consolidation No. 204 | do. | 16 | 29 | 55 | 0 |
| Taggart (Alma, Elkhorn[2]) | Va. | Wise | Dunbar | do. | 6 | 31 | 63 | 0 |
| Millers Creek | Ky | Johnson | Consolidation No. 155 | do. | 25 | 14 | 61 | 0 |
| No. 2 Gas | W. Va. | Kanawha | Point Lick No. 4 | do. | 5 | 45 | 50 | 0 |
| Pond Creek (No. 2 Gas[4]) | Ky. | Pike | Majestic | do. | 13 | 18 | 69 | 0 |
| Powellton | W. Va. | Logan | Elk Creek No. 1 | do. | 9 | 17 | 74 | 0 |
| Clintwood (Matewan[5]) | Va. | Buchanan | Buchanan No. 1 | do. | 24 | 21 | 55 | 0 |
| Eagle | W. Va. | Logan | Mallory Coal No. 3 | do. | 22 | 14 | 64 | 0 |
| Upper Banner | Va. | Dickenson | Clinchfield Coal No. 9 | do. | 29 | 8 | 63 | 0 |
| Lower Banner (Gilbert[6]) | do. | Buchanan | Keen Mountain | do. | 0 | 53 | 36 | 11 |
| Sewell | W. Va. | Fayette | Summerlee | do. | 6 | 13 | 81 | 0 |
| Do. | do. | Wyoming | Wyoming | do. | 4 | 15 | 81 | 0 |
| Sharon (Sewell[7]) | Ohio | Jackson | Sun | do. | 9 | 0 | 84 | 7 |
| Do. | do. | do. | Jackson Iron & Steel | do. | 14 | 10 | 76 | 0 |
| Beckley | W. Va. | Raleigh | Winding Gulf No. 1 | do. | 17 | 6 | 77 | 0 |
| Pocahontas No. 4 | do. | do. | Pemberton Coal & Coke No. 4 | do. | 0 | 5 | 90 | 5 |
| Pocahontas No. 3 | do. | Wyoming | Buckeye No. 3 | do. | 10 | 2 | 88 | 0 |
| High Splint | Ky. | Harlan | Closplint | do. | 53 | 14 | 33 | 0 |
| Pratt | Ala. | Jefferson | Wylam No. 8 | Pottsville (lower half) | 3 | 8 | 89 | 0 |
| Mary Lee | do. | do. | Flat Top | do. | 0 | 0 | 100 | 0 |
| Black Creek | do. | Walker | Empire | do. | 0 | 0 | 100 | 0 |

The exact position of the High Splint, Pratt, Mary Lee, and Black Creek beds with reference to the other beds in this table is not known.

[1] Correlation suggested by D. B. Reger, West Virginia Geological Survey: County Reports, Mineral and Grant Counties, 1924, p. 251.
[2] Correlation by J. S. Hudnall, Mineralogy of Kentucky and Other Papers: The Kentucky Geological Survey, Ser. VI, vol. 27, 1925, pp. 131-133.
[3] A correlation suggested by Hunt, et al (see note 4) makes Elkhorn No. 3 equivalent to Cedar Grove.
[4] Hunt, C. B., Briggs, G. H., Runyan, A. C., and Wesley, G. R., Coal Deposits of Pike County, Kentucky: U. S. Geol. Survey Bull. 876, p. 19, 1937.
[5] Eby, J. B., The Geology and Mineral Resources of Wise County and the Coal-Bearing Portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, 1923, p. 157.
[6] See page 147 of note 5.
[7] See page 267 of note 1.

Although the quality of coke made in the Fischer assay may not be a reliable guide in the selection of coals to be coked commercially the results indicate that the quality of the coke is affected appreciably by the type of coal as well as by the rank of the coal. Figure 10 is a photograph of typical coke residues obtained in the Fischer test. Except for the coals of higher oxygen content the coke residues from the bright coals are considerably more swollen and cellular than are those from the splint coals. Whereas all the cokes from the higher-rank bright coals are completely fused the cokes from the associated splint coals range from only slightly to completely fused.

Relationships that have been established between chemical analyses of the splint and bright coals tested and yields of carbonization products are as follows:

1. The content of fixed carbon determines the yield of coke regardless of the type of coal, as is illustrated in figure 11.

2. Yields of tar and oil increase regularly with increase in volatile-matter content of the coals. A better correlation of tar and oil is obtained if the volatile matter is reduced by an amount equal to 1.3 times the oxygen, as is shown in figures 12 and 13.

3. Yields of tar and oil increase with increase in hydrogen of both splint and bright coals, the yields for coals of equal hydrogen content being greater for the splint coals. (See fig. 14.)

4. Attempts to correlate the yields of gas of the splint and bright coals with their chemical analyses have provided little information. In general, for the bright coals studied, the yields of gas and B.t.u. of gas per pound of coal carbonized increase with increase in the volatile-matter content of the coal.

Agglutinating values were determined for each of the splint and bright coals by the Bureau of Mines agglutinating-value test. With the exception of one high-oxygen coal the agglutinating values of the splint coals tested always are less than those of the associated bright coals. As shown in figure 15 the oxygen in bright coal correlates well with the agglutinating value of the coal. Bright coals of 3.0 to 3.3 percent oxygen (dry, mineral-matter-free coal basis) have the highest agglutinating value, the values decreasing with increase or decrease in the amount of oxygen. The correlation with the oxygen of the splint coals is not good, although in general the agglutinating values decrease with increase in oxygen content.

Oil Algae. - To interpret the properties of cannel-boghead and boghead coals, which contain considerable amounts of oil algae, a sample of oil algae separated from Estonian oil shale was tested by the Fischer low-temperature assay for the yields of carbonization products. The principal products obtained, calculated on a moisture- and mineral-matter-free basis, are tar and oil which comprise 73 percent of the total yield and gas of similar quantity and slightly lower quality than is obtained in the distillation of high-rank bituminous bright coals.

## Correlation of the Analysis of Coal with Products of Carbonization

The proximate analysis is a small-scale carbonization test that separates volatile constituents from solid residue. It was assumed that valuable deductions could be made regarding commercial carbonization of coal, by correlating the carbonizing results at different temperatures in different types of retorts with the proximate analysis and oxygen content.[65] In making this study the following questions were to be answered in the correlation of experimental carbonizing results with the analyses of the coals tested: 1. What constituents of a coal are significant in predicting plant results? 2. What are the major effects of temperature, rate of heating, and size of retort on the coke, gas, and byproducts formed when coal is carbonized in externally heated retorts? 3. Given a proximate and ultimate analysis, what conclusions can be drawn as to the probable results of carbonization?

The results from carbonizing tests of 125 coals, when correlated with the analysis, support the following conclusions:

1. The amount of tar that will form in an externally heated retort is directly proportional to the square of the oxygen-free volatile matter contained in the coal charged to the retort and inversely proportional to the absolute temperature of carbonization. The oxygen-free volatile matter is defined as the percentage of volatile matter minus percentage of oxygen combined with the coal. It excludes the oxygen in the water. The probable tar that will form in the Bureau of Mines-American Gas Association 13-inch retort can be expressed by the following equation:

$$\text{Tar-yield, percent} = 10.4\ V^2 / T.$$

2. The amount of water that will form during destructive distillation at low temperatures is directly proportional to the oxygen content of the coal substance raised to the 1.3 power. The average of 100 distillations in the Fischer retort indicates that the amount of water formed can be expressed by the following formula:

$$\text{Water formed, percent} = 0.35 \times \text{oxygen}^{1.3}$$

3. Heat in gas in B.t.u. per pound of coal is directly proportional to the volatile heating value and inversely proportional to the square root of the volatile matter in the coal. The formation of gas at carbonizing temperatures between 500° and 725°C. is proportional to the average absolute temperature of the wall of the retort raised to the 3.5 power. The formation of gas at carbonizing temperatures between 725° and 1,100°C. is proportional to the square root of the average absolute temperature of the wall of the retort.

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[65] Parry, V. F., Correlation of Analysis of Coal with the Products of Carbonization in Externally Heated Retorts: Bureau of Mines Rept. of Investigations 3482, 1939, 37 pp.

The probable yield for various conditions is expressed by the following equations:

In the temperature range 500° to 725°C.:

$$\text{Heat in gas, B.t.u. per pound of coal} = \frac{C_1B\,(T/1000)^{3.5}}{\sqrt{v}}$$

In the temperature range 725° to 1,100°C.:

$$\text{Heat in gas, B.t.u. per pound of coal} = C_2B\sqrt{\frac{T}{v}}$$

$C_1$ and $C_2$ are constants associated with the shape and the size of the retort and the method of distillation. For the 13- by 26-inch Bureau of Mines-American Gas Association retort, $C_1 = 2.92$ and $C_2 = 0.0952$; for the Fischer assay retort, $C_1 = 2.57$; and for subbituminous coals in continuous vertical retorts, $C_1 = 3.0$ to $3.5$; for coke ovens, $C_2 = 0.105$.

$T$ = absolute temperature of carbonization °K. (°C. + 273).

$B$ = volatile heating value of the coal = gross B.t.u. per pound minus (14,500 x fraction of fixed carbon).

$V$ = oxygen-free volatile matter of coal as charged.

$v$ = percentage volatile of the coal as charged.

Combustibility of Coke in Air

A laboratory method and apparatus for estimating combustibility has been developed. Coarse coke sized between 8- and 10-mesh screen is weighed as it burns and the loss of weight with time is recorded. At 500°C. coals and low-temperature cokes burned fairly rapidly and retort cokes moderately, but beehive and byproduct cokes burned slowly and electrode carbon did not ignite. At 600°C. rates of combustion increased considerably, but the less reactive cokes were affected only moderately. At 700° C. all samples except electrode carbon burned rapidly. At 900°C. rates of combustion were still more rapid, and all of the cokes burned at more nearly the same rate regardless of methods of manufacture; however, even at this temperature the low-temperature cokes burned more rapidly than any of the high-temperature cokes, and these in turn burned more rapidly than the electrode carbon.[66]

## Hydrogenation and Liquefaction

### Continuous Hydrogenation of Some Typical North American Bituminous, Subbituminous and Lignitic Coals

Descriptions have been published of the Bureau's experimental coal-hydrogenation plant and of the development of a satisfactory assay procedure[67] for determining the ease of hydrogenation of American coals. Table 6 contains a summary of yield data[68] on nine coals whose rank ranges from high-volatile bituminous to lignite. The last column of table 6 shows that with one exception (the Mary Lee coal) there is a steady decrease in the yield of oil per ton of coal as mined with decreasing rank. The yield of oil ranges from 64 to 31 tons per 100 tons, or 160 to 78 gallons per ton of coal as mined. The next to the last column of table 6 shows that this decrease in yield of oil with rank is much more gradual when calculated on a moisture-free basis.

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[66] Zane, R. E., and Yancey, H. F., Combustibility of Coke in Air: Bureau of Mines Rept. of Investigations 3499, 1940, 8 pp.

The oils obtained in these assays contain about 20 percent gasoline and 70 percent heavier oil distilling from $200^\circ$ to $330^\circ$ C. The latter can be converted readily into gasoline by well-known procedures that yield about 85 percent by weight or 100 percent by volume based upon the heavy oil. At a later date it is planned to convert all of the higher-boiling fractions of the assay oils to gasoline to test the suitability of the latter for use as motor fuel.

The hydrogen used to produce a ton of oil increases from about 0.12 ton for bituminous coals to about 0.15 ton for lignites. This increase is much smaller than one might have predicted upon considering the oxygen content of the original coals. This result apparently is due to removal of most of the oxygen as carbon dioxide rather than as water, when the oxygen in the coal exceeds 10 percent.

The methods of chemical analysis used in characterizing the products of coal hydrogenation have been described.[69]

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[67] Storch, H. H., and Fieldner, A. C., Coal Hydrogenation, Bureau of Mines Experimental Plant: Mech. Eng., vol. 61, 1939, pp. 605-611.
Hirst, L. L., Hawk, C. O., Sprunk, G. C., Golden, P. L., Pinkel, I. I., Boyer, R. L., Schaeffer, J. R., Kallenberger, R. H., Hamilton, H. A., and Storch, H. H., Liquid-phase Hydrogenation of Pittsburgh-seam Coal: Ind. Eng. Chem., vol. 31, 1939, pp. 869-877.
Storch, H. H., and Fieldner, A. C., Hydrogenation and Liquefaction of American Coals: West Virginia Univ. Bull. Ser. 40, No. 6 II, Tech. Bull. 15, Dec. 1939, pp. 99-133.

[68] Hirst, L. L., Storch, H. H., Fisher, C. H., Sprunk, G. C. Hydrogenation of High-volatile Bituminous Coals. Proximate Analysis and Characterization of Product: Ind. Eng. Chem., vol. 32, 1940, pp. 864-871.

[69] Fein, M. L., Eisner, A., Cooper, H. M., and Fisher, C. H., Solubility Characteristics of Tars and Pitches Produced by Coal Hydrogenation: Ind. Eng. Chem., anal. ed., vol. 11, 1939, pp. 432-438.

TABLE 6. - Summary of assays in experimental plant
(Percentages by weight)

| Coal No. | State | County | Mine | Bed | Rank | Oil yields, percentage of - Moisture- and ash-free | Dry coal | Coal as mined |
|---|---|---|---|---|---|---|---|---|
| 1 | Alabama | Jefferson | Sayreton | Mary Lee | Bit. H.-V.A. | 60 | 54 | 52 |
| 2 | Pennsylvania | Allegheny | Bruceton | Pittsburgh | do. | 70.5 | 65 | 64 |
| 3 | Illinois | Franklin | Orient No. 2 | Illinois No.6 | Bit. H.-V.B. | 70.5 | 65 | 60 |
| 4 | Washington | King | Strain-Upper Diamond | McKay | Bit. H.-V.C. | 68.5 | 66 | 59 |
| 5 | Colorado | Weld | Puritan | Unnamed | Subbit. B | 63 | 60 | 45 |
| 6 | Montana | Rosebud | Colstrip | Rosebud | do. | 60 | 55 | 40 |
| 7 | Wyoming | Sheridan | Monarch No.45 | Monarch | do. | 68.5 | 64 | 49 |
| 8 | North Dakota | Mercer | Beulah, N.D. | Unnamed | Lignite | 54.5 | 50 | 31 |
| 9 | do. | Ward | Velva, N.D. | do. | do. | 52 | 49 | 32 |

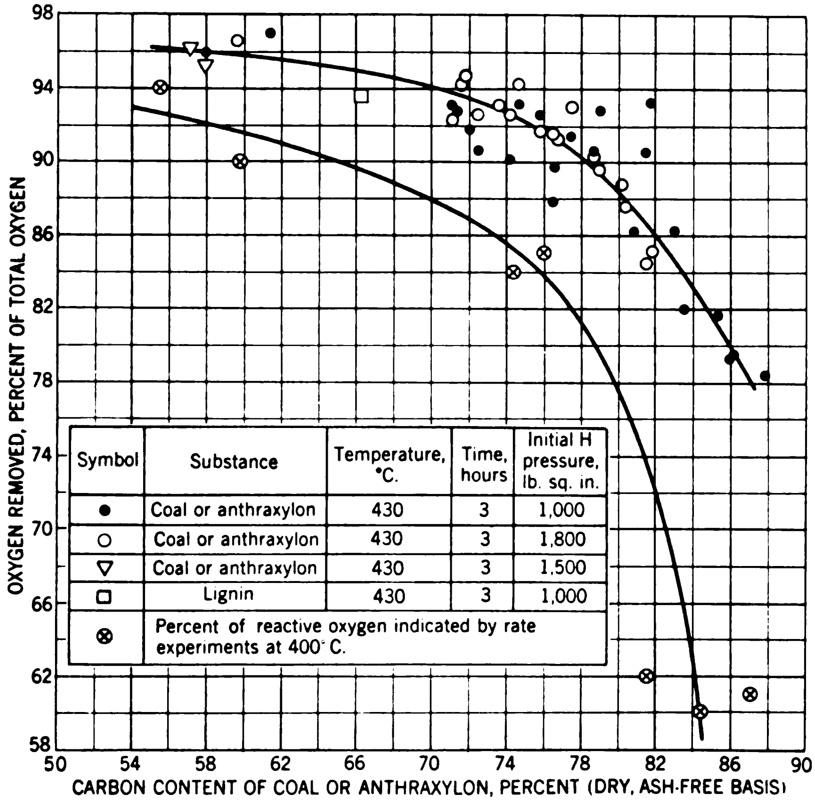

**Figure 16.**- Percentage of total coal oxygen removed from coals and anthraxylon at different rank by hydrogenation.

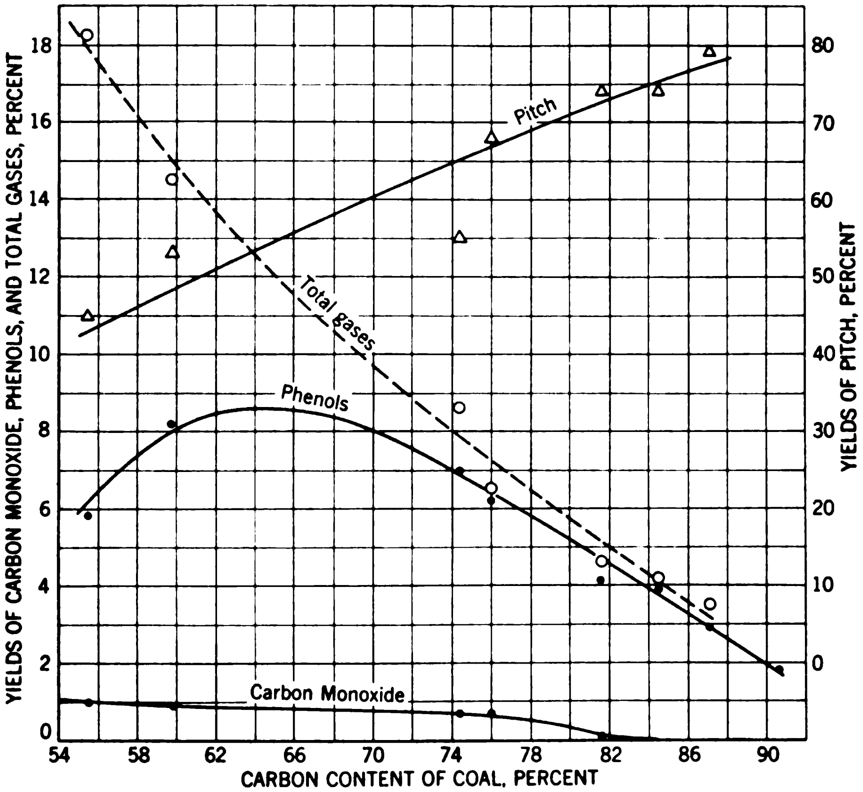

**Figure 17.**- Yields of pitch, carbon monoxide, total gases, and low-boiling phenols produced by hydrogenation at 400° C. (dry, ash-free basis).

## Batch Hydrogenation in Small Autoclaves

### Effect of Rank and Petrography on Hydrogenation of Coal

An extensive survey of the effect of rank and type of coal on its hydrogenation characteristics was completed.[70] The conclusions reached are based on the hydrogenation in small autoclaves of about 130 samples from most of the important coal beds of the United States. These samples were carefully selected by hand, and thin sections were examined under the microscope to determine the relative proportions of opaque and translucent matter. This examination constitutes a petrographic analysis of the coal and is reported as percentage of anthraxylon (the chief constituent of bright coals, translucent in thin section), opaque attritus (coalified plant debris, which is opaque in thin section), translucent attritus (coalified plant debris, which is translucent in thin section), and fusain (opaque charcoal-like fragments).

The results of tests of anthraxylon and translucent attritus showed that except for those samples containing more than 89 percent carbon these constituents liquefy readily and almost completely. This covers a wide range of rank and includes peat, brown coal, lignite, subbituminous coal, and most of the high-volatile bituminous coals. The higher-rank anthraxylons gradually become more resistant to liquefaction as the carbon content increases, and there is no sharp boundary between those that give a high liquefaction yield and those that are relatively inert to hydrogenation.

The low-rank samples are more sensitive to experimental conditions than the bituminous coals. In general, it was found desirable to conduct the experiments with subbituminous and lignitic coals at higher pressures and lower temperatures than those used for the higher-rank coals.

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[70] Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., and Storch, H. H., Hydrogenation of Anthraxylon from Bituminous Coals: Fuel, vol. 18, 1939, pp. 196-203.
Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., and Storch, H. H., Hydrogenation of the Banded Constituents of Coal. Attrital Matter and Anthraxylon: Ind. Eng. Chem., vol. 31, 1939, pp. 1155-1161.
Eisner, A., Sprunk, G. C., Clarke, L., Fisher, C. H., and Storch, H. H., Hydrogenation of Typical Splint Coals: Ind. Eng. Chem., vol. 32, 1940, pp. 73-78.
Eisner, A., Sprunk, G. C., Clarke, L., Fein, M. L., Fisher, C. H., and Storch, H. H., Hydrogenation and Petrography of Some Low-rank Coals from Western United States: Bureau of Mines Rept. of Investigations 3498, 1940, 21 pp.
Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., Fein, M. L., and Storch, H. H., Hydrogenation of Cannel Coals and Their Petrographic Constituents: Fuel, vol. 19, 1940, pp. 84-89, 110-118.
Fisher, C. H., Sprunk, G. C., Eisner, A., Fein, M. L., and Storch, H. H., Hydrogenation and Petrography of Lignites, Subbituminous Coals, and Bituminous Coals from North Dakota, Wyoming, Utah, and Montana: Fuel, vol. 19, 1940, pp. 186-195.
Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., Fein, M. L., and Storch, H. H., Hydrogenation of Anthraxylon (Vitrain) from Peat, Brown Coal, Lignite, Subbituminous Coal, Bituminous Coal, and Anthracite. The Effect of Rank in Coal Hydrogenation: Fuel, vol. 19, 1940, pp. 132-138.

A study of splint coals containing appreciable amounts of opaque attritus shows that from 40 to 80 percent of the opaque matter liquefies. The degree of liquefaction is roughly proportional to the opacity. Hydrogenation of hand-picked fusain (present in most coals to the extent of 2 to 10 percent) shows that 5 to 30 percent of such fusain will liquefy upon hydrogenation.

Spores, resins, and oil algae found in cannel coals in appreciable quantity are readily liquefied under mild hydrogenating conditions. The products obtained from these constituents have a greater percentage of saturated hydrocarbons than those obtained from bright coals.

The yield of residue from hydrogenation of coal can be estimated from the carbon content for coals of the same type (that is, predominantly bright, cannel, or splint). When different types are involved it is best to use the petrographic composition for such estimates.

## Rates and Mechanisms of Coal-hydrogenation Reactions; Effect of Rank

The rates of consumption of hydrogen, removal of oxygen, and liquefaction of one coal as a function of temperature have been measured, and the important coal-hydrogenation reactions were roughly separated and described by an analysis of such data.71/ This work has been extended to include the effect of rank of coal on the rates of these reactions.72/ One bright coal, five anthraxylons that contained 5 to 20 percent oxygen, a low-volatile bituminous coal, a brown coal, peat, lignin, and cellulose were hydrogenated to determine the effect of rank. Although the oxygen ranged from 2.5 to 49 percent there were only small differences in rate of consumption of hydrogen. The rate of consumption was greater for the samples of higher rank.

Most of the oxygen was removed in the first few hours of hydrogenation. The remaining 10 to 40 percent, which was eliminated at a much slower and approximately constant rate, apparently is considerably more stable than that initially removed. The reactive oxygen, indicated from the data on removal of oxygen, ranges from about 94 percent for peat to about 60 percent for intermediate- and low-volatile bituminous coals. By plotting the percentage of reactive oxygen against the carbon of the coal, a curve was obtained (fig. 16) that can be used to estimate the reactive oxygen of bright coals of any rank.

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71/ Storch, H. H., Fisher, C. H., Eisner, A., and Clarke, L., Kinetics of Hydrogen Consumption, Oxygen Removal, and Liquefaction in the Hydrogenation of Pittsburgh-seam Coal: Ind. Eng. Chem., vol. 32, 1940, pp. 346-353.
Storch, H. H., Contact Catalysis in the Hydrogenation of Coal, Coal Tar, and Oil: 12th Report of the Committee on Catalysis, 1940, pp. 82-92, John Wiley & Sons, Inc., New York.

72/ Fisher, C. H., Eisner, A., Clarke, L., Fein, M. L., and Storch, H. H., Kinetics of Hydrogen Consumption, Oxygen Removal, and Liquefaction in Coal Hydrogenation. Effect of Rank: Fuel, vol. 19, 1940, pp. 13-16, 51-55, 67-69.

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The yield of pitch, carbon monoxide, total gases, and low-boiling phenols as a function of the carbon of the coal is shown in figure 17. The yield of pitch increased with increase in carbon (used as an index of rank) of the sample hydrogenated. The yield of phenols boiling at below 220°C. increased with carbon in the coal to about 65 percent carbon and then decreased. Cellulose gave moderate and lignin high yields of low-boiling phenols. The yields of water, total gases, carbon monoxide, and carbon dioxide decreased with increase in carbon.

## Hydrogenation of Banded Constituents of High-Splint Coal

In cooperation with The Pennsylvania State College petrographic analysis was made of a columnar section from the High Splint bed in Harlan County, Ky., and samples of the banded constituents were prepared for batch hydrogenation.[73] For the various fractions of the High Splint coal a straight-line relationship appears to exist between the residue from hydrogenation and the opaque attritus. A similar relationship has previously been established for a series of fractions from the Pittsburgh bed of the same rank. The slope of this line for fractions from the High Splint bed was greater, indicating a higher proportion of liquefaction-resistant opaque matter in this coal. Higher yields of gas were obtained from the High Splint than from the Pittsburgh coal.

## Continuous Hydrogenation of High-temperature Byproduct Coke-oven Tar

The experiments on hydrogenation of tar were made in cooperation with the Jones & Laughlin Steel Corporation of Pittsburgh. The objective of this work was to determine the optimum conditions, yields, and character of products obtainable by the destructive hydrogenation of high-temperature, byproduct coke-oven tar.

Some preliminary experiments were made in a small autoclave to test a number of catalysts. The latter consist of small amounts of materials that markedly expedite the hydrogenation action. For this work on tar hydrogenation 0.05 percent of iodoform was used as a catalyst. The plant tests showed that it was necessary to use two phases or stages of hydrogenation. In the first or liquid-phase stage the original tar is mixed with 0.05 percent iodoform and the mixture pumped, with hydrogen, into a heated high-pressure reaction vessel or converter. In the second or vapor-phase stage the oil product from the first stage is vaporized in a stream of hydrogen, and the vapors passed through a body of catalyst particles consisting of granules of alumina gel impregnated with 25 percent of their weight of ammonium molybdate. The over-all yield of oils boiling in the gasoline range was 68 percent by weight, or 97 percent by volume of the original tar. Chemical analysis of these oils showed that they should be useful as solvents in the paint and varnish industries.

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[73] Wright, C. C., and Sprunk, G. C., Hydrogenation of the Petrographic Constituents of High Splint Seam Coal: Pennsylvania State Coll. Min. Ind. Exp. Sta. Bull. 28, 1939, 23 pp.

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## Gasoline Substitutes From Coal

Technologic and economic phases of the production of motor fuel from coal were discussed.[74] Benzol obtained as a byproduct in the manufacture of coke is used as a motor fuel. The total possible yield of benzol from the coal made into coke in the United States in 1937 would have replaced 0.7 percent of the 24 billion gallons of gasoline produced that year. If all of the 440 million tons of bituminous coal mined in the United States in 1937 had been put through byproduct ovens (that is high-temperature carbonization) the benzol obtained would have been equivalent to only 4.6 percent of the gasoline produced from petroleum. By low-temperature carbonization of 100 million tons of bituminous coal 1,000 million gallons of motor fuel, or about 4 percent of the gasoline, could have been produced.

Motor fuel can be produced from coal by hydrogenation or by synthesis at an estimated cost of 16 to 18 cents a gallon; therefore, the cost to the consumer would be materially higher than the cost of gasoline obtained from petroleum. Large-scale hydrogenation of coal in the United States would require an extended period of research on our particular coals to determine which coals would give the best yields and which locations would prove most economically desirable. In almost all foreign instances of manufacture of motor fuel from coal at present the operation is aided by direct subsidy or by preference, such as remission of taxes imposed on motor fuels.

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[74] Fieldner, A. C., Davis, J. D., and Storch, H. H., Gasoline Substitutes from Coal: Hearing before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-Sixth Congress, on H. Res. 290 and H. R. 7372, to promote the conservation of petroleum; to provide for cooperation with the States in preventing the waste of petroleum; to create an office of petroleum conservation; to amend the act of February 22, 1935, as amended; and for other purposes, pp. 277-28